Laboratory Manual

# PHYSICS

## Class XI



राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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# FOREWORD

The National Council of Educational Research and Training (NCERT) is the apex body concerning all aspects of refinement of School Education. It has recently developed textual material in Physics for Higher Secondary stage which is based on the National Curriculum Framework (NCF)–2005. NCF recommends that children's experience in school education must be linked to the life outside school so that learning experience is joyful and fills the gap between the experience at home and in community. It recommends to diffuse the sharp boundaries between different subjects and discourages rote learning. The recent development of syllabi and textual material is an attempt to implement this basic idea. The present Laboratory Manual will be complementary to the textbook of Physics for Class XI. It is in continuation to the NCERT's efforts to improve upon comprehension of concepts and practical skills among students. The purpose of this manual is not only to convey the approach and philosophy of the practical course to students and teachers but to provide them appropriate guidance for carrying out experiments in the laboratory. The manual is supposed to encourage children to reflect on their own learning and to pursue further activities and questions. Of course, the success of this effort also depends on the initiatives to be taken by the principals and teachers to encourage children to carry out experiments in the laboratory and develop their thinking and nurture creativity.

The methods adopted for performing the practicals and their evaluation will determine how effective this practical book will prove to make the children's life at school a happy experience, rather than a source of stress and boredom. The practical book attempts to provide space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience. It is hoped that the material provided in this manual will help students in carrying out laboratory work effectively and will encourage teachers to introduce some open-ended experiments at the school level.

Yash Pal
21.5.08

PROFESSOR YASH PAL
*Chairperson*
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New Delhi
*21 May 2008*

# PREFACE

The development of the present laboratory manual is in continuation to the NCERT's efforts to support comprehension of concepts of science and also facilitate inculcation of process skills of science. This manual is complementary to the *Physics Textbook for Class XI* published by NCERT in 2006 following the guidelines enumerated in National Curriculum Framework (NCF)-2005. One of the basic criteria for validating a science curriculum recommended in NCF–2005, is that 'it should engage the learner in acquiring the methods and processes that lead to the generation and validation of scientific knowledge and nurture the natural curiosity and creativity of the child in science'. The broad objective of this laboratory manual is to help the students in performing laboratory based exercises in an appropriate manner so as to develop a spirit of enquiry in them. It is envisaged that students would be given all possible opportunities to raise questions and seek their answers from various sources.

The physics practical work in this manual has been presented under four sections (i) experiments (ii) activities (iii) projects and (iv) demonstrations. A write-up on major skills to be developed through practical work in physics has been given in the beginning which includes discussion on objectives of practical work, experimental errors, logarithm, plotting of graphs and general instructions for recording experiments.

Experiments and activities prescribed in the NCERT syllabus (covering CBSE syllabus also) of Class XI are discussed in detail. Guidelines for conducting each experiment has been presented under the headings (i) apparatus and material required (ii) principle (iii) procedure (iv) observations (v) calculations (vi) result (vii) precautions (viii) sources of error. Some important experimental aspects that may lead to better understanding of result are also highlighted in the discussion. Some questions related to the concepts involved have been raised so as to help the learners in self assessment. Additional experiments/activities related to a given experiment are put forth under suggested additional experiments/activities at the end.

A number of project ideas, including guidelines are suggested so as to cover all types of topics that may interest young learners at higher secondary level.

A large number of demonstration experiments have also been suggested for the teachers to help them in classroom transaction. Teachers should encourage participation of the students in setting up and improvising apparatus, in discussions and give them opportunity to analyse the experimental data to arrive at conclusions.

Appendices have been included with a view to try some innovative experiments using improvised apparatus. Data section at the end of the book enlists a number of useful Tables of physical constants.

Each experiment, activity, project and demonstration suggested in this manual have been tried out by the experts and teachers before incorporating them. We sincerely hope that students and teachers will get motivated to perform these experiments supporting various concepts of physics thereby enriching teaching learning process and experiences.

It may be recalled that NCERT brought out laboratory manual in physics for senior secondary classes earlier in 1989. The write-ups on activities, projects, demonstrations and appendices included in physics manual published by NCERT in 1989 have been extensively used in the development of the present manual.

We are grateful to the teachers and subject experts who participated in the workshops organised for the review and refinement of the manuscript of this laboratory manual.

I acknowledge the valuable contributions of Prof. B.K. Sharma and other team members who contributed and helped in finalising this manuscript. I also acknowledge with thanks the dedicated efforts of Sri R. Joshi who looked after the coordinatorship after superannuation of Professor B.K. Sharma in June, 2008.

We warmly welcome comments and suggestions from our valued readers for further improvement of this manual.

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# CONTENTS

# I: MAJOR SKILLS IN PHYSICS PRACTICAL WORK

## I 1.1 INTRODUCTION

The higher secondary stage is the most crucial and challenging stage of school education because at this stage the general undifferentiated curriculum changes into a discipline-based, content area-oriented course. At this stage, students take up physics as a discipline, with the aim of pursuing their future careers either in basic sciences or in science-based professional courses like engineering, medicine, information technology etc.

Physics deals with the study of matter and energy associated with the inanimate as well as the animate world. Although all branches of science require experimentation, controlled laboratory experiments are of central importance in physics. The basic purpose of laboratory experiments in physics, in general, is to verify and validate the concepts, principles and hypotheses related to the physical phenomena. Only doing this does not help the learners become independent thinkers or investigate on their own. In view of this, laboratory work is very much required and encouraged in different ways.These may include not only doing experiments but investigate different facets involved in doing experiments. Many activities as well as project work will therefore ensure that the learners are able to construct and reconstruct their ideas on the basis of first hand experiences through investigation in the laboratory. Besides, learners will be able to integrate experimental work with theory which they are studying at higher secondary stage through their environment.

The history of science reveals that many significant discoveries have been made while carrying out experiments. In the growth of physics, experimental work is as important as the theoretical understanding of a phenomenon. Performing experiments by one's own hands in a laboratory is important as it generates a feeling of direct involvement in the process of generating knowledge. Carrying out experiments in a laboratory personally and analysis of the data obtained also help in inculcating scientific temper, logical thinking, rational outlook, sense of self-confidence, ability to take initiative, objectivity, cooperative attitude, patience, self-reliance, perseverance, etc. Carrying out experiments also develop manipulative, observational and reporting skills.

The 'National Curriculum Framework' (NCF-2005) and the Syllabus for Secondary and Higher Secondary stages (NCERT, 2006) have therefore, laid considerable emphasis on laboratory work as an integral part of the teaching-learning process.

NCERT has already published *Physics Textbook for Classes XII*, based on the new syllabus. In order to supplement the conceptual understanding and to integrate the laboratory work in physics and contents of the physics course, this laboratory manual has been developed. The basic purpose of a laboratory manual in physics is to motivate the students towards practical work by involving them in "process-oriented performance" learning (as opposed to 'product-or result-oriented performance') and to infuse life into the sagging practical work in schools. In view of the alarming situation with regard to the conduct of laboratory work in schools, it is hoped that this laboratory manual will prove to be of considerable help and value.

## I 1.2 OBJECTIVES OF PRACTICAL WORK

Physics deals with the understanding of natural phenomena and applying this understanding to use the phenomena for development of technology and for the betterment of society. Physics practical work involves **'learning by doing'**. It clarifies concepts and lays the seed for enquiry.

Careful and stepwise observation of sequences during an experiment or activity facilitate personal investigation as well as small group or team learning.

A practical physics course should enable students to do experiments on the fundamental laws and principles, and gain experience of using a variety of measuring instruments. Practical work enhances basic learning skills. Main skills developed by practical work in physics are discussed below.

### I 1.2.1 MANIPULATIVE SKILLS

The learner develops **manipulative skills** in practical work if she/he is able to

(i) *comprehend* the theory and objectives of the experiment,

(ii) *conceive* the procedure to perform the experiment,

(iii) *set-up* the apparatus in proper order,

(iv) *check* the suitability of the equipment, apparatus, tool regarding their working and functioning,

(v) *know* the limitations of measuring device and find its least count, error etc.,

(vi) *handle* the apparatus carefully and cautiously to avoid any damage to the instrument as well as any personal harm,

(vii) *perform* the experiment systematically.

(viii) *make* precise observations,

(ix) *make* proper substitution of data in formula, keeping proper units (SI) in mind,

(x) *calculate* the result accurately and express the same with appropriate significant figures, justified by the degree of accuracy of the instrument,

(xi) *interpret* the results, verify principles and draw conclusions; and

(xii) *improvise* simple apparatus for further investigations by selecting appropriate equipment, apparatus, tools, materials.

## 1.2.2 OBSERVATIONAL SKILLS

The learner develops **observational skills** in practical work if she/he is able to

(i) *read* about instruments and measure physical quantities, keeping least count in mind,

(ii) *follow* the correct sequence while making observations,

(iii) *take* observations carefully in a systematic manner; and

(iv) *minimise* some errors in measurement by repeating every observation independently a number of times.

## 1.2.3 DRAWING SKILLS

The learner develops **drawing skills** for recording observed data if she/he is able to

(i) *make* schematic diagram of the apparatus,

(ii) *draw* ray diagrams, circuit diagrams correctly and label them,

(iii) *depict* the direction of force, tension, current, ray of light etc, by suitable lines and arrows; and

(iv) *plot* the graphs correctly and neatly by choosing appropriate scale and using appropriate scale.

## 1.2.4 REPORTING SKILLS

The learner develops **reporting skills** for presentation of observation data in practical work if she/he is able to

(i) *make* a proper presentation of aim, apparatus, formula used, principle, observation table, calculations and result for the experiment,

(ii) support the presentation with labelled diagram using appropriate symbols for components,

(iii) *record* observations systematically and with appropriate units in a tabular form wherever desirable,

(iv) *follow* sign conventions while recording measurements in experiments on ray optics,

(v) *present* the calculations/results for a given experiment alongwith proper significant figures, using appropriate symbols, units, degree of accuracy,

(vi) *calculate* error in the result,

(vii) *state* limitations of the apparatus/devices,

(viii) *summarise* the findings to reject or accept a hypothesis,

(ix) *interpret* recorded data, observations or graphs to draw conclusion; and

(x) *explore* the scope of further investigation in the work performed.

However, the most valued skills perhaps are those that pertain to the realm of creativity and investigation.

## I 1.3 SPECIFIC OBJECTIVES OF LABORATORY WORK

Specific objectives of laboratory may be classified as process-oriented performance skills and product-oriented performance skills.

### I 1.3.1 PROCESS - ORIENTED PERFORMANCE SKILLS

The learner develops process-oriented performance skills in practical work if she/he is able to

(i) *select* appropriate tools, instruments, materials, apparatus and chemicals and handle them appropriately,

(ii) *check* for the working of apparatus beforehand,

(iii) *detect* and rectify instrumental errors and their limitations,

(iv) *state* the principle/formula used in the experiment,

(v) *prepare* a systematic plan for taking observations,

(vi) *draw* neat and labelled diagram of given apparatus/ray diagram/circuit diagram wherever needed,

(vii) *set up* apparatus for performing the experiment,

(viii) *handle* the instruments, chemicals and materials carefully,

(ix) *identify* the factors that will influence the observations and take appropriate measures to minimise their effects,

(x) *perform* experiment within stipulated time with reasonable speed, accuracy and precision,

(xi) *represent* the collected data graphically and neatly by choosing appropriate scale and neatly, using proper scale,

(xii) *interpret* recorded data, observations, calculation or graphs to draw conclusion,

(xiii) *report* the principle involved, procedure and precautions followed in performing the experiment,

(xiv) *dismantle* and reassemble the apparatus; and

(xv) *follow* the standard guidelines of working in a laboratory.

## I 1.3.2 PRODUCT - ORIENTED PERFORMANCE SKILLS

The learner develops product-oriented performance skills in practical work if she/he is able to

(i) *identify* various parts of the apparatus and materials used in the experiment,

(ii) *set-up* the apparatus according to the plan of the experiment,

(iii) *take* observations and record data systematically so as to facilitate graphical or numerical analysis,

(iv) *present* the observations systematically using graphs, calculations etc. and draw inferences from recorded observations,

(v) *analyse* and interpret the recorded observations to finalise the results; and

(vi) *accept or reject* a hypothesis based on the experimental findings.

## I 1.4 EXPERIMENTAL ERRORS

The ultimate aim of every experiment is to measure directly or indirectly the value of some physical quantity. The very process of measurement brings in some uncertainties in the measured value. THERE IS NO MEASUREMENT WITHOUT ERRORS. As such the value of a physical quantity obtained from some experiments may be different from its standard or true value. Let *'a'* be the experimentally

observed value of some physical quantity, the 'true' value of which is '$a_0$'. The difference $(a - a_0) = e$ is called the error in the measurement. Since $a_0$, the true value, is mostly not known and hence it is not possible to determine the error $e$ in absolute terms. However, it is possible to estimate the likely magnitude of $e$. The estimated value of error is termed as **experimental error**. The error can be due to least count of the measuring instrument or a mathematical relation involving least count as well as the variable. The quality of an experiment is determined from the experimental uncertainty of the result. Smaller the magnitude of uncertainty, closer is the experimentally measured value to the true value. **Accuracy is a measure of closeness of the measured value to the true value.** On the other hand, if a physical quantity is measured repeatedly during the same experiment again and again, the values so obtained may be different from each other. This dispersion or spread of the experimental data is a measure of the precision of the experiment/instrument. A smaller spread in the experimental value means a more precise experiment. **Thus, accuracy and precision are two different concepts. Accuracy is a measure of the nearness to truth, while precision is a measure of the dispersion in experimental data.** It is quite possible that a high precision experimental data may be quite inaccurate (if there are large systematic errors present). A rough estimate of the maximum spread is related to the least count of the measuring instrument.

Experimental errors may be categorised into two types: (a) systematic, and (b) random. Systematic errors may arise because of (i) faulty instruments (like zero error in vernier callipers), (ii) incorrect method of doing the experiment, and (iii) due to the individual who is conducting the experiment. **Systematic errors** are those errors for which corrections can be applied and in principle they can be removed. Some common systematic errors: (i) Zero error in micrometer screw and vernier callipers readings. (ii) The 'backlash' error. When the readings on a scale of microscope are taken by rotating the screw first in one direction and then in the reverse direction, the reading is less than the actual distance through which the screw is moved. To avoid this error all the readings must be taken while rotating the screw in the same direction. (iii) The 'bench error' or 'index correction'. When distances measured on the scale of an optical bench do not correspond to the actual distances between the optical devices, addition or substraction of the difference is necessary to obtain correct values. (iv) If the relation is linear, and if the systematic error is constant, the straight-line graph will get shifted keeping the slope unchanged, but the intercept will include the systematic error.

In order to find out if the result of some experiments contains systematic errors or not, the same quantity should be measured by a different method. If the values of the same physical quantity obtained by two different methods differ from each other by a large amount, then there is a possibility of systematic error. The experimental value,

after corrections for systematic errors still contain errors. All such residual errors whose origin cannot be traced are called **random errors**. Random errors cannot be avoided and there is no way to find the exact value of random errors. However, their magnitude may be reduced by measuring the same physical quantity again and again by the same method and then taking the mean of the measured values (For details, see *Physics Textbook for Class XI, Part I, Chapter 2;* NCERT, 2006).

While doing an experiment in the laboratory, we measure different quantities using different instruments having different values of their least counts. It is reasonable to assume that the maximum error in the measured value is not more than the least count of the instrument with which the measurement has been made. As such in the case of simple quantities measured directly by an instrument, the least count of the instrument is generally taken as the maximum error in the measured value. If a quantity having a true value $A_o$ is measured as $A$ with the instrument of least count $a$, then

$$A = (A_0 \pm a)$$

$$= A_0 (1 \pm a / A_0)$$

$$= A_0 (1 \pm f_a)$$

where $f_a$ is called the maximum fractional error of $A$. Similarly, for another measured quantity $B$, we have

$$B = B_0 (1 \pm f_b)$$

Now some quantity, say $Z$, is calculated from the measured value of $A$ and $B$, using the formula

$Z = A.B$

We now wish to calculate the expected total uncertainty (or the likely maximum error) in the calculated value of $Z$. We may write

$Z = A.B$

$$= A_0 (1 \pm f_a).B_0 (1 \pm f_b)$$

$$= A_0 B_0 (1 \pm f_a \pm f_b \pm f_a f_b)$$

$\simeq A_0 B_0 \left[1 \pm (f_a + f_b)\right]$, [If $f_a$ and $f_b$ are very small quantities, their product $f_a f_b$ can be neglected]

or $Z \approx Z_0 [1 \pm f_z]$

where the fractional error $f_z$ in the value of Z may have the largest value of $|f_a + f_b|$.

On the other hand, if the quantity Y to be calculated is given as

$$Y = A/B = A_0(1 \pm f_a)/B_0(1 \pm f_b)$$

$$= Y_0(1 \pm f_a)(1 \pm f_b)^{-1}; \qquad \left[Y_0 = \frac{A_0}{B_0}\right]$$

$$= Y_0(1 \pm f_a)(1 \pm f_b + f_b^2)$$

$$= Y_0(1 \pm f_a)(1 \pm f_b)$$

$$\sim Y_0\left[1 \pm (f_a + f_b)\right]$$

or $Y = Y_0\ (1 \pm f_y)$, with $f_y = f_a + f_b$, where the maximum fractional uncertainty $f_y$ in the calculated value of Y is again $|f_a + f_b|$. Note that the maximum fractional uncertainty is always additive.

Taking a more general case, where a quantity P is calculated from several measured quantities *x, y, z* etc., using the formula $P = x^a y^b z^c$, it may be shown that the maximum fractional error $f_p$ in the calculated value of *P* is given as

$$f_p = |a|\, f_x + |b|\, f_y + |c|\, f_z$$

It may be observed that the value of the overall fractional error $f_p$ in the quantity *P* depends on the fractional errors $f_x$, $f_y$, $f_z$ etc. of each measured quantity, as well as on the power *a, b, c* etc., of these quantities which appear in the formula. As such, the quantity which has the highest power in the formula, should be measured with the least possible fractional error, so that the contribution of $|a|\, f_x + |b|\, f_y + |c|\, f_z$ to the overall fraction error $f_p$ are of the same order of magnitude.

Let us calculate the expected uncertainty (or experimental error) in a quantity that has been determined using a formula which involves several measured physical parameters.

A quantity *Y*, Young's Modulus of elasticity is calculated using the formula

$$Y = \frac{MgL^3}{4bd^3\delta}$$

where $M$ is the mass, $g$ is the acceleration due to gravity, $L$ is the length of a metallic bar of rectangular cross-section, with breadth $b$, and thickness $d$, and $\delta$ is the depression (or sagging) from the horizontal in the bar when a mass $M$ is suspended from the middle point of the bar, supported at its two ends (Fig. I 1.1).

Now in an actual experiment, mass $M$ may be taken as 1 kg. Normally the uncertainty in mass is not more than 1 g. It means that the least count of the ordinary balance used for measuring mass is 1 g. As such, the fractional error $f_M$ is 1g/1kg or $f_M = 1 \times 10^{-3}$.

Let us assume that the value of acceleration due to gravity $g$ is 9.8 m/s$^2$ and it does not contain any significant error. Hence there will be no fractional error in $g$, i.e., $f_g = 0$. Further the length $L$ of the bar is, say, 1 m and is measured by an ordinary metre scale of least count of 1 mm = 0.001 m. The fractional error $f_L$ in the length $L$ is therefore,

$f_L$ = 0.001 m / 1m = $1 \times 10^{-3}$.

Next the breadth $b$ of the bar which is, say, 5 cm is measured by a vernier callipers of least count 0.01 cm. The fractional error $f_b$ is then,

$f_b$ = 0.01 cm / 5 cm = 0.002 = $2 \times 10^{-3}$.

Similarly, for the thickness $d$ of the bar, a screw gauge of least count 0.001 cm is used. If, a bar of thickness, say, 0.2 cm is taken so that

$f_d$ = 0.001 cm / 0.2 cm = 0.005 = $5 \times 10^{-3}$.

Finally, the depression $\delta$ which is measured by a spherometer of least count 0.001 cm, is about 5 mm, so that

$f_\delta$ = 0.001 cm / 0.5 cm = 0.002 = $2 \times 10^{-3}$.

Having calculated the fractional errors in each quantity, let us calculate the fractional error in $Y$ as

$$f_Y = (1)\, f_M + (1)\, f_g + (3)\, f_L + (1)\, f_b + (3)\, f_d + (1)\, f_\delta$$

$$= 1 \times (1 \times 10^{-3}) + 1 \times 0 + 3 \times (1 \times 10^{-3}) + 1 \times (2 \times 10^{-3}) + 3 \times (5 \times 10^{-3}) + 1 \times (2 \times 10^{-3})$$

$$= 1 \times 10^{-3} + 3 \times 10^{-3} + 2 \times 10^{-3} + 15 \times 10^{-3} + 2 \times 10^{-3}$$

or, $f_Y = 22 \times 10^{-3} = 0.022$.

Hence the possible fractional error (or uncertainty) is $f_y \times 100 = 0.022 \times 100 = 2.2\%$. It may be noted that, for a good experiment, the contribution to the maximum fractional error $f_y$ in the calculated value of $Y$ contributed by various terms, i.e., $f_M$, $3f_L$, $f_b$, $3f_d$, and $f_\delta$ should be of the same order of magnitude. It should not happen that one of these quantities becomes so large that the value of $f_y$ is determined by that factor only. If this happens, then the measurement of other quantities will become insignificant. It is for this reason that the length $L$ is measured by a metre scale which has a large least count (0.1 cm) while smaller quantities $d$ and $\delta$ are measured by screw gauge and

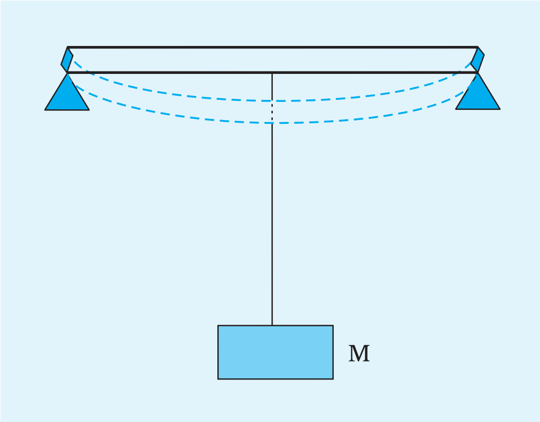



***Fig. 1.1:*** *A mass M is suspended from the metallic bar supported at its two ends*

spherometer, respectively, which have smaller least count (0.001 cm). Also those quantities which have higher power in the formula, like $d$ and $L$ should be measured more carefully with an instrument of smaller least count.

The end product of most of the experiments is the measured value of some physical quantity. This measured value is generally called the result of the experiment. In order to report the result, three main things are required. These are – the measured value, the expected uncertainty in the result (or experimental error) and the unit in which the quantity is expressed. Thus the **measured value** is expressed alongwith the error and proper unit as the value $\pm$ error (units).

Suppose a result is quoted as A ± a (unit).

This implies that the value of $A$ is estimated to an accuracy of 1 part in $A/a$, both $A$ and $a$ being numbers. It is a general practice to include all digits in these numbers that are reliably known plus the first digit that is uncertain. Thus, all reliable digits plus the first uncertain digit together are called SIGNIFICANT FIGURES. The significant figures of the measured value should match with that of the errors. In the present example assuming Young Modulus of elasticity, $Y = 18.2 \times 10^{10}$ N/m$^2$; (please check this value by calculating $Y$ from the given data) and

error, $\dfrac{\Delta Y}{Y} = f_y$

$\Delta Y = f_y . Y$

$= 0.022 \times 18.2 \times 10^{10}$ N/m$^2$

$= 0.39 \times 10^{10}$ N/m$^2$, where $\Delta Y$ is experimental error.

So the quoted value of $Y$ should be $(18.2 \pm 0.4) \times 10^{10}$ N/m$^2$.

## I 1.5 LOGARITHMS

The logarithm of a number to a given base is the index of the power to which the base must be raised to equal that number.

If $a^x = N$ then $x$ is called logarithm of $N$ to the base $a$, and is denoted by $\log_a N$ [read as log $N$ to the base $a$]. For example, $2^4 = 16$. The log of 16 to the base 2 is equal to 4 or, $\log_2 16 = 4$.

In general, for a number we use logarithm to the base 10. Here log 10 = 1, log 100 = log $10^2$ and so on. Logarithm to base 10 is usually written as log.

## (i) COMMON LOGARITHM

Logarithm of a number consists of two parts:

(i) Characteristic — It is the integral part [whole of natural number]

(ii) Mantissa — It is the fractional part, generally expressed in decimal form (mantissa is always positive).

## (ii) HOW TO FIND THE CHARACTERISTIC OF A NUMBER?

The characteristic depends on the magnitude of the number and is determined by the position of the decimal point. For a number greater than 1, the characteristic is positive and is less than the number of digits to the left of the decimal point.

For a number smaller than one (i.e., decimal fraction), the characteristic is negative and one more than the number of zeros between the decimal point and the first digit. For example, characteristic of the number

| | | |
|---|---|---|
| 430700 is 5; | 4307 is 3; | 43.07 is 1; |
| 4.307 is 0; | 0.4307 is –1; | 0.04307 is –2; |
| 0.0004307 is –4 | 0.00004307 is –5. | |

The negative characteristic is usually written as $\bar{1}, \bar{2}, \bar{4}, \bar{5}$ etc and read as bar 1, bar 2, etc.

## I 1.5.1 HOW TO FIND THE MANTISSA OF A NUMBER?

The value of mantissa depends on the digits and their order and is independent of the position of the decimal point. As long as the digits and their order is the same, the mantissa is the same, whatever be the position of the decimal point.

The logarithm Tables 1 and 2, on pages 266–269, give the mantissa only. They are usually meant for numbers containing four digits, and if a number consists of more than four figures, it is rounded off to four figures after determining the characteristic. To find mantissa, the tables are used in the following manner :

(i) The first two significant figures of the number are found at the extreme left vertical column of the table wherein the number lying between 10 and 99 are given. The mantissa of the figures which are less than 10 can be determined by multiplying the figures by 10.

(ii) Along the horizontal line in the topmost column the figures

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

are given. These correspond to the third significant figure of the given number.

(iii) Further right column under the figures (digits) corresponds to the fourth significant figures.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|

**Example 1 :** Find the logarithm of 278.6.

**Answer :** The number has 3 figures to the left of the decimal point. Hence, its characteristic is 2. To find the mantissa, ignore the decimal point and look for 27 in the first vertical column. For 8, look in the central topmost column. Proceed from 27 along a horizontal line towards the right and from 8 vertically downwards. The two lines meet at a point where the number 4440 is written. This is the mantissa of 278. Proceed further along the horizontal line and look vertically below the figure 6 in difference column. You will find the figure 9. Therefore, the mantissa of 2786 is 4440 + 9 = 4449.

Hence, the logarithm of 278.6 is 2.4449 ( or log 278.6 = 2.4449).

**Example 2** : Find the logarithm of 278600.

**Answer :** The characteristic of this number is 5 and the mantissa is the same as in Example 1, above. We can find the mantissa of only four significant figures. Hence, we neglect the last 2 zero.

$\therefore$ log 278600 = 5.4449

**Example 3** : Find the logarithm of 0.00278633.

**Answer** : The characteristic of this number is $\bar{3}$, as there are two zeros following the decimal point. We can find the mantissa of only four significant figures. Hence, we neglect the last 2 figures (33) and find the mantissa of 2786 which is 4449.

$\therefore$ log 0.00278633 = $\bar{3}.4449$

When the last figure of a number consisting of more than 4 significant figures is equal to or more than 5, the figure next to the left of it is raised by one and so on till we have only four significant figures and if the last figure is less than 5, it is neglected as in the above example.

If we have the number 2786.58, the last figure is 8. Therefore, we shall raise the next in left figure to 6 and since 6 is greater than 5, we shall raise the next figure 6 to 7 and find the logarithm of 2787.

## 1.5.2 ANTILOGARITHMS

The number whose logarithm is $x$ is called antilogarithm and is denoted by antilog $x$.

Thus, since log 2 = 0.3010, then antilog 0.3010 = 2.

**Example 1 :** Find the number whose logarithm is 1.8088.

**Answer :** For this purpose, we use antilogarithms table which is used for fractional part.

(i) In Example 1, fractional part is 0.8088. The first two figures from the left are 0.80, the third figure is 8 and the fourth figure is also 8.

(ii) In the table of the antilogarithms, first look in the vertical column for 0.80. In this horizontal row under the column headed by 8, we find the number 6427 at the intersection. It means the number for mantissa 0.808 is 6427.

(iii) In continuation of this horizontal row and under the mean difference column on the right under 8, we find the number 12 at the intersection. Adding 12 to 6427 we get 6439. Now 6439 is the figure of which .8088 is the mantissa.

(iv) The characteristic is 1. This is one more than the number of digits in the integral part of the required number. Hence, the number of digits in the integral part of the required number = 1 + 1 =2. The required number is 64.39 i.e., antilog 1.8088 = 64.39.

**Example 2 :** Find the antilog of $\bar{2}.8088$.

**Answer :** As the characteristic is $\bar{2}$, there should be one zero on the right of decimal in the number, hence antilog $\bar{2}.8088 = 0.06439$.

Properties of logarithms:

(i) $\log_a mn = \log_a m + \log_a n$

(ii) $\log_a m/n = \log_a m - \log_a n$

(iii) $\log_a m^n = n \log_a m$

The definition of logarithm:

$\log_a 1 = 0$ [since $a^0 = 1$]

The log of 1 to any base is zero,

and $\log_a a = 1$ [since the logarithm of the base to itself is 1, $a^1 = a$]

## 1.6 NATURAL SINE / COSINE TABLE

To find the sine or cosine of some angles we need to refer to Tables of trignometric functions. Natural sine and cosine tables are given in the DATA SECTION (Tables 3 and 4, Pages 270–273). Angles are given usually in degrees and minutes, for example : 35°6′ or 35.1°.

### 1.6.1 READING OF NATURAL SINE TABLE

Suppose we wish to know the value of sin 35°10′. You may proceed as follows:

(i) Open the Table of natural sines.

(ii) Look in the first column and locate 35°. Scan horizontally, move from value 0.5736 rightward and stop under the column where 6′ is marked. You will stop at 0.5750.

(iii) But it is required to find for 10′.

The difference between 10′ and 6′ is 4′. So we look into the column of mean difference under 4′ and the corresponding value is 10. Add 10 to the last digits of 0.5750 and we get 0.5760.

Thus, sin (35°10′) is 0.5760.

### 1.6.2 READING OF NATURAL COSINE TABLE

Natural cosine tables are read in the same manner. However, because of the fact that value of cos θ decrease as θ increases, the mean difference is to be subtracted. For example, cos 25° = 0.9063. To read the value of cosine angle 25°40′, i.e., cos 25°40′, we read for cos 25°36′ = 0.9018. Mean difference for 4′ is 5 which is to be subtracted from the last digits of 0.9018 to get 0.9013. Thus, cos 25°40′ = 0.9013.

### 1.6.3 READING OF NATURAL TANGENTS TABLE

Natural Tangents table are read the same way as the natural sine table.

## 1.7 PLOTTING OF GRAPHS

A graph pictorially represents the relation between two variable quantities. It also helps us to visualise experimental data at a glance and shows the relation between the two quantities. If two physical quantities *a* and *b* are such that a change made by us in *a* results in a change in *b*, then *a* is called independent variable and *b* is called dependent variable. For example, when you change the length of the pendulum, its time period changes. Here length is independent variable while time period is dependent variable.

A graph not only shows the relation between two variable quantities in pictorial form, it also enables verification of certain laws (such as Boyle's law) to find the mean value from a large number of observations, to extrapolate/interpolate the value of certain quantities beyond the limit of observation of the experiment, to calibrate or graduate a given instrument for measurement and to find the maximum and minimum values of the dependent variable.

Graphs are usually plotted on a graph paper sheet ruled in millimetre/centimetre squares. For plotting a graph, the following steps are observed:

(i) Identify the independent variable and dependent variable. Represent the independent variable along the x-axis and the dependent variable along the y-axis.

(ii) Determine the range of each of the variables and count the number of big squares available to represent each, along the respective axis.

(iii) Choice of scale is critical for plotting of a graph. Ideally, the smallest division on the graph paper should be equal to the least count of measurement or the accuracy to which the particular parameter is known. Many times, for clarity of the graph, a suitable fraction of the least count is taken as equal to the smallest division on the graph paper.

(iv) Choice of origin is another point which has to be done judiciously. Generally, taking (0,0) as the origin serves the purpose. But such a choice is to be adopted generally when the relation between variables begins from zero or it is desired to find the zero position of one of the variables, if its actual determination is not possible. However, in all other cases the origin need not correspond to zero value of the variable. It is, however, convenient to represent a round number nearest to but less than the smallest value of the corresponding variable. On each axis mark only the values of the variable in round numbers.

(v) The scale markings on x-and y-axis should not be crowded. Write the numbers at every fifth cm of the axis. Write also the units of the quantity plotted. Use scientific representations of the numbers, i.e., write the number with decimal point following the first digit and multiply the number by appropriate power of ten. The scale conversion may also be written at the right or left corner at the top of the graph paper.

(vi) Write a suitable caption below the plotted graph mentioning the names or symbols of the physical quantities involved. Also indicate the scales taken along both the axes on the graph paper.

(vii) When the graph is expected to be a straight line, generally 6 to 7 readings are enough. Time should not be wasted in taking a very large number of observations. The observations must be covering all available range evenly.

(viii) If the graph is a curve, first explore the range by covering the entire range of the independent variable in 6 to 7 steps. Then try to guess where there will be sharp changes in the curvature of the curve. Take more readings in those regions. For example, when there is either a maximum or minimum, more readings are needed to locate the exact point of extremum, as in the determination of angle of minimum deviation ($\delta m$) you may need to take more observations near about $\delta m$.

(ix) Representation of "data" points also has a meaning. The size of the spread of plotted point must be in accordance with the accuracy of the data. Let us take an example in which the plotted point is represented as ⊙, a point with a circle around it. The central dot is the value of measured data. The radius of circle of 'x' or 'y' side gives the size of uncertainty. If the circle radius is large, it will mean as if uncertainty in data is more. Further such a representation tells that accuracy along x- and y-axis are the same. Some other representations used which give the same meaning as above are ⊡, ◬, ■, ▲, ×, etc.

In case, uncertainty along the x-axis and y-axis are different, some of the notations used are † (accuracy along x-axis is more than that on y-axis); ┼ (accuracy along x-axis is less than that on y-axis). ⌖, ▯, ⬮, ▮, ▬ are some of such other symbols. You can design many more on your own.

(x) After all the data points are plotted, it is customary to fit a smooth curve judiciously by hand so that the maximum number of points lie on or near it and the rest are evenly distributed on either side of it. Now a days computers are also used for plotting graphs of a given data.

## I 1.7.1 SLOPE OF A STRAIGHT LINE

The slope $m$ of a straight line graph AB is defined as

$$m = \frac{\Delta y}{\Delta x}$$

where $\Delta y$ is the change in the value of the quantity plotted on the y-axis, corresponding to the change $\Delta x$ in the value of the quantity plotted on the x-axis. It may be noted that the sign of $m$ will be positive when both $\Delta x$ and $\Delta y$ are of the same sign, as shown in Fig. I 1.2. On the other hand, if $\Delta y$ is of opposite sign (i.e., $y$ decreases when $x$ increases) than that of $\Delta x$, the value of the slope will be negative. This is indicated in Fig. I 1.3.

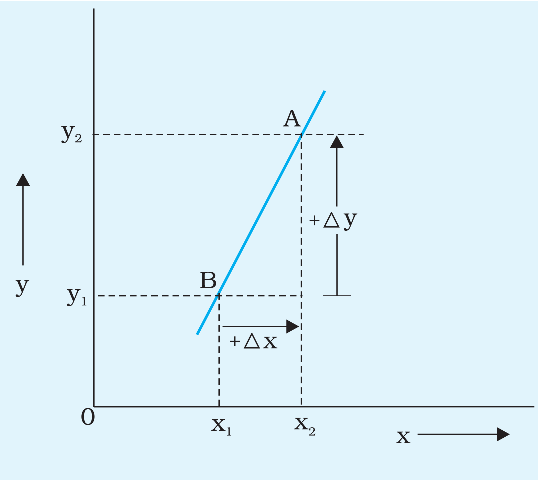



*Fig. 1.2* Value of slope is positive

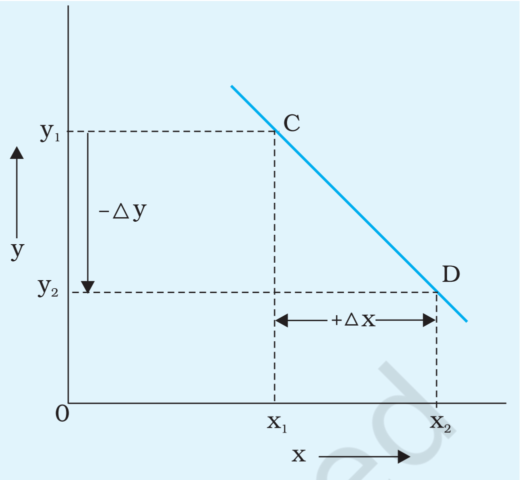



*Fig. 1.3* Value of slope is negative

Further, the slope of a given straight line has the same value, for all points on the line. It is because the value of $y$ changes by the same amount for a given change in the value of $x$, at every point of the straight line, as shown in Fig. I 1.4. Thus, for a given straight line, the slope is fixed.

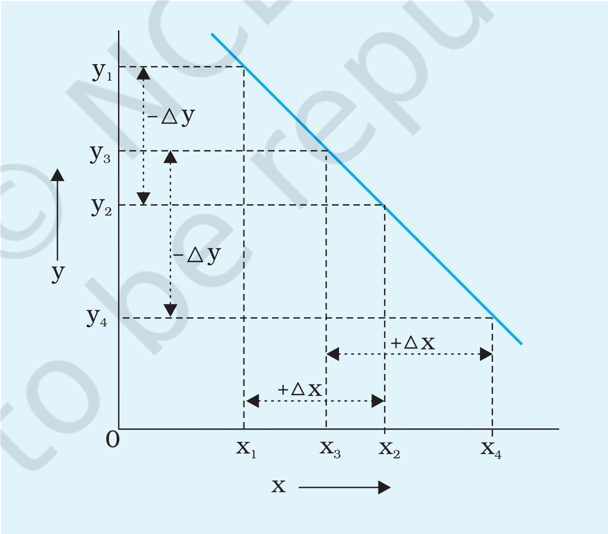



*Fig. 1.4:* Slope is fixed for a given straight line

While calculating the slope, always choose the x-segment of sufficient length and see that it represents a round number of the variable. The corresponding interval of the variable on $y$-segment is then measured and the slope is calculated. Generally, the slope should not have more than two significant digits. The values of the slope and the intercepts, if there are any, should be written on the graph paper.

Do not show slope as tan$\theta$. Only when scales along both the axes are identical slope is equal to tan$\theta$. Also keep in mind that slope of a graph has physical significance, not geometrical.

Often straight-line graphs expected to pass through the origin are found to give some intercepts. Hence, whenever a linear relationship is expected, the slope should be used in the formula instead of the mean of the ratios of the two quantities.

## I 1.7.2 SLOPE OF A CURVE AT A GIVEN POINT ON IT

As has been indicated, the slope of a straight line has the same value at each point. However, it is not true for a curve. As shown in Fig. I 1.5, the slope of the curve CD may have different values of slope at points A′ , A, A′, etc.

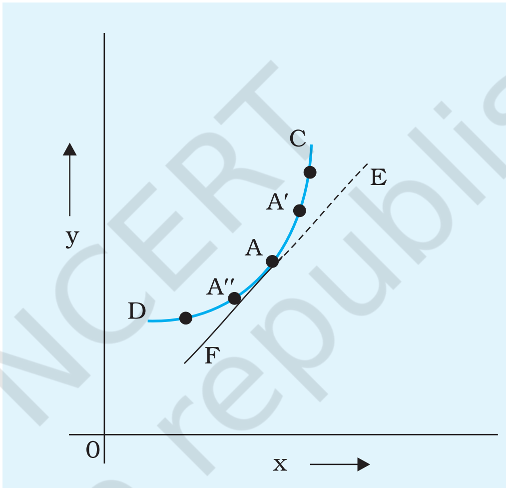



***Fig. I 1.5:*** *Tangent at a point A*

Therefore, in case of a non-straight line curve, we talk of the slope at a particular point. The slope of the curve at a particular point, say point A in Fig. I 1.5, is the value of the slope of the line EF which is the tangent to the curve at point A. As such, in order to find the slope of a curve at a given point, one must draw a tangent to the curve at the desired point.

In order to draw the tangent to a given curve at a given point, one may use a plane mirror strip attached to a wooden block, so that it stands perpendicular to the paper on which the curve is to be drawn. This is illustrated in Fig. I 1.6 (a) and Fig. I 1.6 (b). The plane mirror strip MM′ is placed at the desired point A such that the image D′ A of the part DA of the curve appears in the mirror strip as continuation of

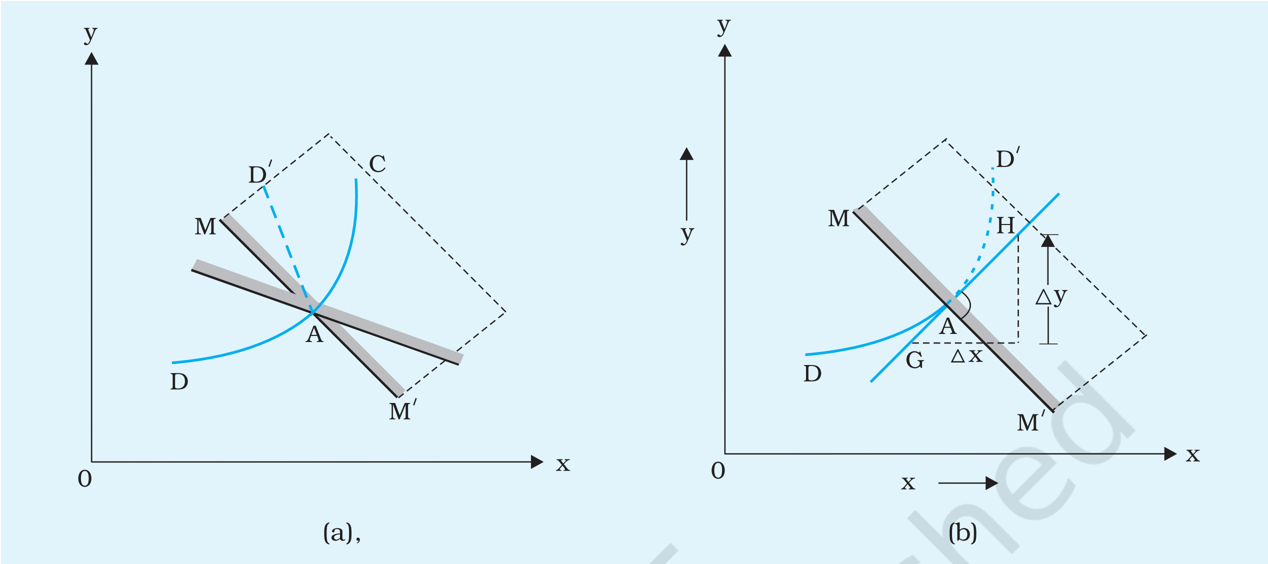



***Fig. 1.6 (a), (b):*** *Drawing tangent at point A using a plane mirror*

DA. In general, the image D′ A will not appear to be smoothly joined with the part of the curve DA as shown in Fig. I 1.6 (a).

Next rotate the mirror strip MM′ , keeping its position at point A fixed. The image D′ A in the mirror will also rotate. Now adjust the position of MM′ such that DAD′ appears as a continuous, smooth curve as shown in Fig. I 1.6 (b). Draw the line MAM′ along the edge of the mirror for this setting. Next using a protractor, draw a perpendicular GH to the line MAM′ at point A.

GAH is the line, which is the required tangent to the curve DAC at point A. The slope of the tangent GAH (i.e., $\Delta y / \Delta x$) is the slope of the curve CAD at point A. The above procedure may be followed for finding the slope of any curve at any given point.

## I 1.8 General Instructions for Performing Experiments

1. The students should thoroughly understand the principle of the experiment. The objective of the experiment and procedure to be followed should be clear before actually performing the experiment.
2. The apparatus should be arranged in proper order. To avoid any damage, all apparatus should be handled carefully and cautiously. Any accidental damage or breakage of the apparatus should be immediately brought to the notice of the concerned teacher.

3. Precautions meant for each experiment should be observed strictly while performing it.

4. Repeat every observation, a number of times, even if measured value is found to be the same. The student must bear in mind the proper plan for recording the observations. Recording in tabular form is essential in most of the experiments.

5. Calculations should be neatly shown (using log tables wherever desired). The degree of accuracy of the measurement of each quantity should always be kept in mind, so that final result does not reflect any fictitious accuracy. The result obtained should be suitably rounded off.

6. Wherever possible, the observations should be represented with the help of a graph.

7. Always mention the result in proper SI unit, if any, along with experimental error.

## I 1.9 GENERAL INSTRUCTIONS FOR RECORDING EXPERIMENTS

A neat and systematic recording of the experiment in the practical file is very important for proper communication of the outcome of the experimental investigations. The following heads may usually be followed for preparing the report:

DATE:-------- EXPERIMENT NO:---------- PAGE NO.-------

### AIM

State clearly and precisely the objective(s) of the experiment to be performed.

### APPARATUS AND MATERIAL REQUIRED

Mention the apparatus and material used for performing the experiment.

### DESCRIPTION OF APPARATUS INCLUDING MEASURING DEVICES (OPTIONAL)

Describe the apparatus and various measuring devices used in the experiment.

### TERMS AND DEFINITIONS OR CONCEPTS (OPTIONAL)

Various important terms and definitions or concepts used in the experiment are stated clearly.

## PRINCIPLE / THEORY

Mention the principle underlying the experiment. Also, write the formula used, explaining clearly the symbols involved (derivation not required). Draw a circuit diagram neatly for experiments/activities related to electricity and ray diagrams for light.

## PROCEDURE (WITH IN-BUILT PRECAUTIONS)

Mention various steps followed with in-built precautions actually observed in setting the apparatus and taking measurements in a sequential manner.

## OBSERVATIONS

Record the observations in tabular form as far as possible, neatly and without any overwriting. Mention clearly, on the top of the observation table, the least counts and the range of each measuring instrument used.

However, if the result of the experiment depends upon certain conditions like temperature, pressure etc., then mention the values of these factors.

## CALCULATIONS AND PLOTTING GRAPH

Substitute the observed values of various quantities in the formula and do the computations systematically and neatly with the help of logarithm tables. Calculate experimental error.

Wherever possible, use the graphical method for obtaining the result.

## RESULT

State the conclusions drawn from the experimental observations. [Express the result of the physical quality in proper significant figures of numerical value along with appropriate SI units and probable error]. Also mention the physical conditions like temperature, pressure etc., if the result happens to depend upon them.

## PRECAUTIONS

Mention the precautions actually observed during the course of the experiment/activity.

## SOURCES OF ERROR

Mention the possible sources of error that are beyond the control of the individual while performing the experiment and are liable to affect the result.

## DISCUSSION

The special reasons for the set up etc., of the experiment are to be mentioned under this heading. Also mention any special inferences which you can draw from your observations or special difficulties faced during the experimentation. These may also include points for making the experiment more accurate for observing precautions and, in general, for critically relating theory to the experiment for better understanding of the basic principle involved.

# EXPERIMENT 1

## AIM

Use of Vernier Callipers to

(i) measure diameter of a small spherical/cylindrical body,

(ii) measure the dimensions of a given regular body of known mass and hence to determine its density; and

(iii) measure the internal diameter and depth of a given cylindrical object like beaker/glass/calorimeter and hence to calculate its volume.

## APPARATUS AND MATERIAL REQUIRED

Vernier Callipers, Spherical body, such as a pendulum bob or a glass marble, rectangular block of known mass and cylindrical object like a beaker/glass/calorimeter

## DESCRIPTION OF THE MEASURING DEVICE

1. A Vernier Calliper has two scales–one main scale and a Vernier scale, which slides along the main scale. The main scale and Vernier scale are divided into small divisions though of different magnitudes.

The main scale is graduated in cm and mm. It has two fixed jaws, A and C, projected at right angles to the scale. The sliding Vernier scale has jaws (B, D) projecting at right angles to it and also the main scale and a metallic strip (N). The zero of main scale and Vernier scale coincide when the jaws are made to touch each other. The jaws and metallic strip are designed to measure the distance/ diameter of objects. Knob P is used to slide the vernier scale on the main scale. Screw S is used to fix the vernier scale at a desired position.

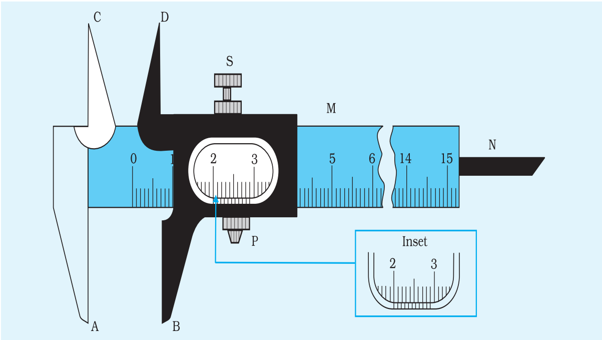



***Fig. E 1.1*** *Vernier Calliper*

2. The least count of a common scale is 1mm. It is difficult to further subdivide it to improve the least count of the scale. A vernier scale enables this to be achieved.

## PRINCIPLE

The difference in the magnitude of one main scale division (M.S.D.) and one vernier scale division (V.S.D.) is called the least count of the instrument, as it is the smallest distance that can be measured using the instrument.

$$n \text{ V.S.D.} = (n-1) \text{ M.S.D.}$$

**Formulas Used**

(a) Least count of vernier callipers

$$= \frac{\textit{the magnitude of the smallest division on the main scale}}{\textit{the total number of small divisions on the vernier scale}}$$

(b) Density of a rectangular body = $\frac{mass}{volume} = \frac{m}{V} = \frac{m}{l.b.h}$ where $m$ is its mass, $l$ its length, $b$ its breadth and $h$ the height.

(c) The volume of a cylindrical (hollow) object $V = \pi r^2 h' = \frac{\pi D'^2}{4}.h'$ where $h'$ is its internal depth, $D'$ is its internal diameter and $r$ is its internal radius.

## PROCEDURE

**(a) Measuring the diameter of a small spherical or cylindrical body.**

1. Keep the jaws of Vernier Callipers closed. Observe the zero mark of the main scale. It must perfectly coincide with that of the vernier scale. If this is not so, account for the zero error for all observations to be made while using the instrument as explained on pages 26-27.
2. Look for the division on the vernier scale that coincides with a division of main scale. Use a magnifying glass, if available and note the number of division on the Vernier scale that coincides with the one on the main scale. Position your eye directly over the division mark so as to avoid any parallax error.
3. Gently loosen the screw to release the movable jaw. Slide it enough to hold the sphere/cylindrical body gently (without any undue pressure) in between the lower jaws AB. The jaws should be perfectly perpendicular to the diameter of the body. Now, gently tighten the screw so as to clamp the instrument in this position to the body.
4. Carefully note the position of the zero mark of the vernier scale against the main scale. Usually, it will not perfectly coincide with

any of the small divisions on the main scale. Record the main scale division just to the left of the zero mark of the vernier scale.

5. Start looking for exact coincidence of a vernier scale division with that of a main scale division in the vernier window from left end (zero) to the right. Note its number (say) N, carefully.

6. Multiply 'N' by least count of the instrument and add the product to the main scale reading noted in step 4. Ensure that the product is converted into proper units (usually cm) for addition to be valid.

7. Repeat steps 3-6 to obtain the diameter of the body at different positions on its curved surface. Take three sets of reading in each case.

8. Record the observations in the tabular form [Table E 1.1(a)] with proper units. Apply zero correction, if need be.

9. Find the arithmetic mean of the corrected readings of the diameter of the body. Express the results in suitable units with appropriate number of significant figures.

**(b) Measuring the dimensions of a regular rectangular body to determine its density.**

1. Measure the length of the rectangular block (if beyond the limits of the extended jaws of Vernier Callipers) using a suitable ruler. Otherwise repeat steps 3-6 described in (a) after holding the block lengthwise between the jaws of the Vernier Callipers.

2. Repeat steps 3-6 stated in (a) to determine the other dimensions (breadth $b$ and height $h$) by holding the rectangular block in proper positions.

3. Record the observations for length, breadth and height of the rectangular block in tabular form [Table E 1.1 (b)] with proper units and significant figures. Apply zero corrections wherever necessary.

4. Find out the arithmetic mean of readings taken for length, breadth and height separately.

**[c] Measuring the internal diameter and depth of the given beaker (or similar cylindrical object) to find its internal volume.**

1. Adjust the upper jaws CD of the Vernier Callipers so as to touch the wall of the beaker from inside without exerting undue pressure on it. Tighten the screw gently to keep the Vernier Callipers in this position.

2. Repeat the steps 3-6 as in (a) to obtain the value of internal diameter of the beaker/calorimeter. Do this for two different (angular) positions of the beaker.

3. Keep the edge of the main scale of Vernier Callipers, to determine the depth of the beaker, on its peripheral edge. This should be done in such a way that the tip of the strip is able to go freely inside the beaker along its depth.

4. Keep sliding the moving jaw of the Vernier Callipers until the strip just touches the bottom of the beaker. Take care that it does so while being perfectly perpendicular to the bottom surface. Now tighten the screw of the Vernier Callipers.

5. Repeat steps 4 to 6 of part (a) of the experiment to obtain depth of the given beaker. Take the readings for depth at different positions of the breaker.

6. Record the observations in tabular form [Table E 1.1 (c)] with proper units and significant figures. Apply zero corrections, if required.

7. Find out the mean of the corrected readings of the internal diameter and depth of the given beaker. Express the result in suitable units and proper significant figures.

## OBSERVATIONS

**(i) Least count of Vernier Callipers (Vernier Constant)**

1 main scale division (MSD) = 1 mm = 0.1 cm

Number of vernier scale divisions, N = 10

10 vernier scale divisions = 9 main scale divisions

1 vernier scale division = 0.9 main scale division

Vernier constant = 1 main scale division – 1 vernier scale division

= (1– 0.9) main scale divisions

= 0.1 main scale division

Vernier constant ($V_C$) = 0.1 mm = 0.01 cm

Alternatively,

$$\text{Vernier constant} = \frac{1\text{MSD}}{\text{N}} = \frac{1\ \text{mm}}{10}$$

Vernier constant ($V_C$) = 0.1 mm = 0.01 cm

**(ii) Zero error and its correction**

When the jaws A and B touch each other, the zero of the Vernier should coincide with the zero of the main scale. If it is not so, the instrument is said to possess zero error (e). Zero error may be

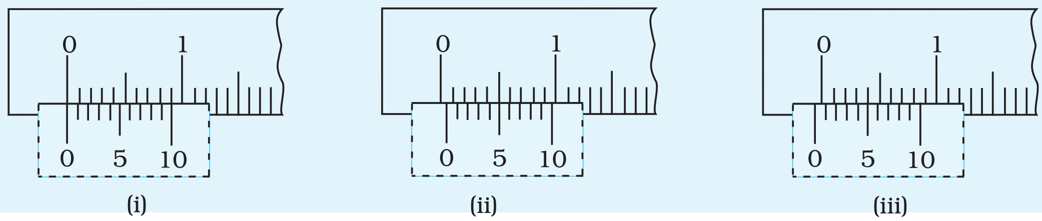



***Fig. E 1.2:*** Zero error (i) no zero error (ii) positive zero error (iii) negative zero error

positive or negative, depending upon whether the zero of vernier scale lies to the right or to the left of the zero of the main scale. This is shown by the Fig. E1.2 (ii) and (iii). In this situation, a correction is required to the observed readings.

**(iii) Positive zero error**

Fig E 1.2 (ii) shows an example of positive zero error. From the figure, one can see that when both jaws are touching each other, zero of the vernier scale is shifted to the right of zero of the main scale (This might have happened due to manufacturing defect or due to rough handling). This situation makes it obvious that while taking measurements, the reading taken will be more than the actual reading. Hence, a correction needs to be applied which is proportional to the right shift of zero of vernier scale.

In ideal case, zero of vernier scale should coincide with zero of main scale. But in Fig. E 1.2 (ii), $5^{th}$ vernier division is coinciding with a main scale reading.

$\therefore$Zero Error = + 5 × Least Count = + 0.05 cm

Hence, the zero error is positive in this case. For any measurements done, the zero error (+ 0.05 cm in this example) should be 'subtracted' from the observed reading.

$\therefore$True Reading = Observed reading – (+ Zero error)

**(iv) Negative zero error**

Fig. E 1.2 (iii) shows an example of negative zero error. From this figure, one can see that when both the jaws are touching each other, zero of the vernier scale is shifted to the left of zero of the main scale. This situation makes it obvious that while taking measurements, the reading taken will be less than the actual reading. Hence, a correction needs to be applied which is proportional to the left shift of zero of vernier scale.

In Fig. E 1.2 (iii), $5^{th}$ vernier scale division is coinciding with a main scale reading.

$\therefore$Zero Error = – 5 × Least Count

= – 0.05 cm

Note that the zero error in this case is considered to be negative. For any measurements done, the negative zero error, (–0.05 cm in this example) is also substracted 'from the observed reading', though it gets added to the observed value.

∴True Reading = Observed Reading – (– Zero error)

**Table E 1.1 (a): Measuring the diameter of a small spherical/ cylindrical body**

| S. No. | Main Scale reading, $M$ (cm/mm) | Number of coinciding vernier division, $N$ | Vernier scale reading, $V = N \times V_c$ (cm/mm) | Measured diameter, $M + V$ (cm/mm) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |

Zero error, e = ± ... cm

Mean observed diameter = ... cm

Corrected diameter = Mean observed diameter – Zero Error

**Table E 1.1 (b) : Measuring dimensions of a given regular body (rectangular block)**

| Dimension | S. No. | Main Scale reading, $M$ (cm/mm) | Number of coinciding vernier division, $N$ | Vernier scale reading, $V = N \times V_c$ (cm/mm) | Measured dimension $M + V$ (cm/mm) |
|---|---|---|---|---|---|
| Length ($l$) | 1<br>2<br>3 | | | | |
| Breadth ($b$) | 1<br>2<br>3 | | | | |
| Height ($h$) | 1<br>2<br>3 | | | | |

Zero error = ± ... mm/cm

Mean observed length = ... cm, Mean observed breadth = ... cm

Mean observed height = ... cm

Corrected length = ... cm; Corrected breath = ... cm;

Corrected height = ...cm

**Table E 1.1 (c) : Measuring internal diameter and depth of a given beaker/ calorimeter/ cylindrical glass**

| Dimension | S. No. | Main Scale reading, $M$ (cm/mm) | Number of coinciding vernier division, $N$ | Vernier scale reading, $V = N \times V_C$ (cm/mm) | Measured diameter/depth, $M + V$ (cm/mm) |
|---|---|---|---|---|---|
| Internal diameter ($D'$) | 1<br>2<br>3 | | | | |
| Depth ($h'$) | 1<br>2<br>3 | | | | |

Mean diameter = ... cm

Mean depth= ... cm

Corrected diameter = ... cm

Corrected depth = ... cm

## CALCULATION

**(a) Measurement of diameter of the sphere/ cylindrical body**

Mean measured diameter, $D_o = \dfrac{D_1 + D_2 + ... + D_6}{6}$ cm

$D_o$ = ... cm = ... × $10^{-2}$ m

Corrected diameter of the given body, $D = D_o - (\pm e)$ = ... × $10^{-2}$ m

**(b) Measurement of length, breadth and height of the rectangular block**

Mean measured length, $l_o = \dfrac{l_1 + l_2 + l_3}{3}$ cm

$l_o$ = ... cm = ... × $10^{-2}$ m

Corrected length of the block, $l = l_o - (\pm e)$ = ... cm

Mean observed breadth, $b_o = \dfrac{b_1 + b_2 + b_3}{3}$

Mean measured breadth of the block, $b_0$ = ... cm = ... × $10^{-2}$ m

Corrected breadth of the block,

$b = b_O - (\pm e)$ cm = ... × $10^{-2}$ m

Mean measured height of block $h_o = \dfrac{h_1 + h_2 + h_3}{3}$

Corrected height of block $h = h_o - (\pm e) = \ldots$ cm

Volume of the rectangular block,

$$V = lbh = \ \ldots \text{ cm}^3 = \ \ldots \ \times 10^{-6} \text{ m}^3$$

Density $\rho$ of the block,

$$\rho = \frac{m}{V} = \ldots \text{ kg m}^{-3}$$

**(c) Measurement of internal diameter of the beaker/glass**

Mean measured internal diameter, $D_o = \dfrac{D_1 + D_2 + D_3}{3}$

$$D_o = \ldots \text{ cm} = \ldots \times 10^{-2} \text{ m}$$

Corrected internal diameter,

$$D = D_o - (\pm e) = \ldots \text{ cm} = \ldots \times 10^{-2} \text{ m}$$

Mean measured depth of the beaker, $h_o = \dfrac{h_1 + h_2 + h_3}{3}$

$$= \ldots \text{ cm} = \ldots \times 10^{-2} \text{ m}$$

Corrected measured depth of the beaker

$$\text{h} = h_o - (\pm e) \ldots \text{ cm} = \ldots \times 10^{-2} \text{ m}$$

Internal volume of the beaker

$$V = \frac{\pi \text{D}^2 \text{h}}{4} = \ldots \times 10^{-6} \text{ m}^3$$

## RESULT

(a) Diameter of the spherical/ cylindrical body,

$$D = \ldots \times 10^{-2} \text{m}$$

(b) Density of the given rectangular block,

$$\rho = \ldots \text{ kg m}^{-3}$$

(c) Internal volume of the given beaker

$$V' = \ldots \text{ m}^3$$

## PRECAUTIONS

1. If the vernier scale is not sliding smoothly over the main scale, apply machine oil/grease.
2. Screw the vernier tightly without exerting undue pressure to avoid any damage to the threads of the screw.
3. Keep the eye directly over the division mark to avoid any error due to parallax.
4. Note down each observation with correct significant figures and units.

## SOURCES OF ERROR

Any measurement made using Vernier Callipers is likely to be incorrect if-

(i) the zero error in the instrument placed is not accounted for; and

(ii) the Vernier Callipers is not in a proper position with respect to the body, avoiding gaps or undue pressure or both.

## DISCUSSION

1. A Vernier Callipers is necessary and suitable only for certain types of measurement where the required dimension of the object is freely accessible. It cannot be used in many situations. e.g. suppose a hole of diameter 'd' is to be drilled into a metal block. If the diameter $d$ is small - say 2 mm, neither the diameter nor the depth of the hole can be measured with a Vernier Callipers.
2. It is also important to realise that use of Vernier Callipers for measuring length/width/thickness etc. is essential only when the desired degree of precision in the result (say determination of the volume of a wire) is high. It is meaningless to use it where precision in measurement is not going to affect the result much. For example, in a simple pendulum experiment, to measure the diameter of the bob, since $L >> d$.

## SELF ASSESSMENT

1. One can undertake an exercise to know the level of skills developed in making measurements using Vernier Callipers. Objects, such as *bangles/kangan*, marbles whose dimensions can be measured indirectly using a thread can be used to judge the skill acquired through comparison of results obtained using both the methods.
2. How does a vernier decrease the least count of a scale.

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Determine the density of glass/metal of a (given) cylindrical vessel.
2. Measure thickness of doors and boards.
3. Measure outer diameter of a water pipe.

**ADDITIONAL EXERCISE**

1. In the vernier scale normally used in a Fortin's barometer, 20 VSD coincide with 19 MSD (each division of length 1 mm). Find the least count of the vernier.
2. In vernier scale (angular) normally provided in spectrometers/sextant, 60 VSD coincide with 59 MSD (each division of angle 1°). Find the least count of the vernier.
3. How would the precision of the measurement by Vernier Callipers be affected by increasing the number of divisions on its vernier scale?
4. How can you find the value of π using a given cylinder and a pair of Vernier Callipers?

   [**Hint** : Using the Vernier Callipers, - Measure the diameter $D$ and find the circumference of the cylinder using a thread. Ratio of circumference to the diameter ($D$) gives π.]
5. How can you find the thickness of the sheet used for making of a steel tumbler using Vernier Callipers?

   [**Hint:** Measure the internal diameter ($D_i$) and external diameter ($D_o$) of the tumbler. Then, thickness of the sheet $D_t = (D_o - D_i)/2$.]

# EXPERIMENT 2

## AIM

Use of screw gauge to

(a) measure diameter of a given wire,

(b) measure thickness of a given sheet; and

(c) determine volume of an irregular lamina.

## APPARATUS AND MATERIAL REQUIRED

Wire, metallic sheet, irregular lamina, millimetre graph paper, pencil and screw gauge.

## DESCRIPTION OF APPARATUS

With Vernier Callipers. you are usually able to measure length accurately up to 0.1 mm. More accurate measurement of length, up to 0.01 mm or 0.005 mm, may be made by using a screw gauge. As such a Screw Gauge is an instrument of higher precision than a Vernier Callipers. You might have observed an ordinary screw [Fig E2.1 (a)]. There are threads on a screw. The separation between any two consecutive threads is the same. The screw can be moved backward or forward in its nut by rotating it anti-clockwise or clockwise [Fig E2.1(b)].

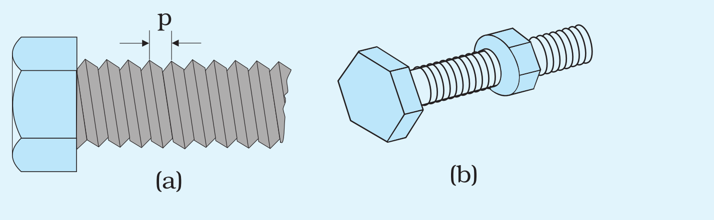



***Fig.E 2.1*** *A screw (a) without nut (b) with nut*

The distance advanced by the screw when it makes its one complete rotation is the separation between two consecutive threads. This distance is called the Pitch of the screw. Fig. E 2.1(a) shows the pitch (*p*) of the screw. It is usually 1 mm or 0.5 mm. Fig. E 2.2 shows a screw gauge. It has a screw 'S' which advances forward or backward as one rotates the head C through rachet R. There is a linear

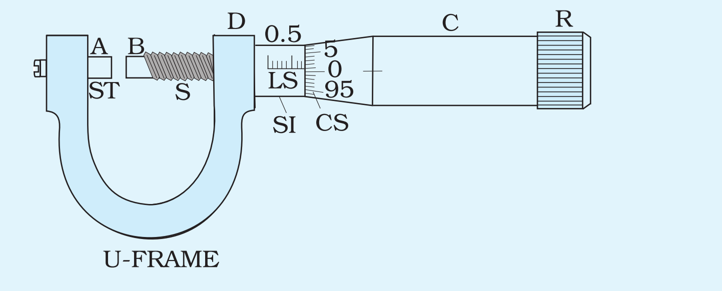



***Fig.E 2.2:*** *View of a screw gauge*

scale 'LS' attached to limb D of the U frame. The smallest division on the linear scale is 1 mm (in one type of screw gauge). There is a circular scale CS on the head, which can be rotated. There are 100 divisions on the circular scale. When the end B of the screw touches the surface A of the stud ST, the zero marks on the main scale and the circular scale should coincide with each other.

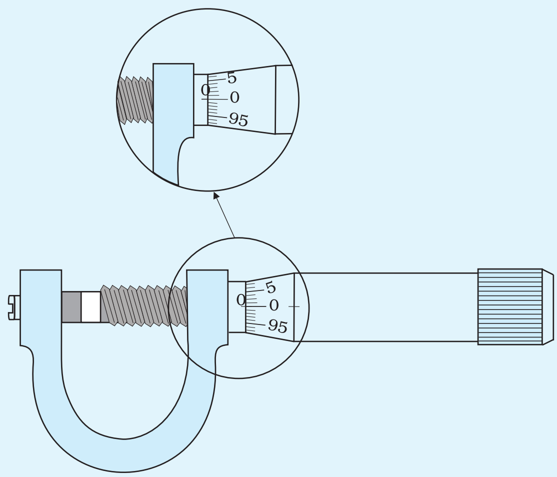
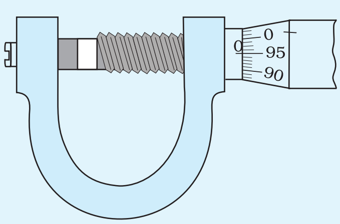



***Fig.E 2.3:*** *A screw gauge with no zero error*




(a)

***Fig.E 2.4 (a):*** *Showing a positive zero error*

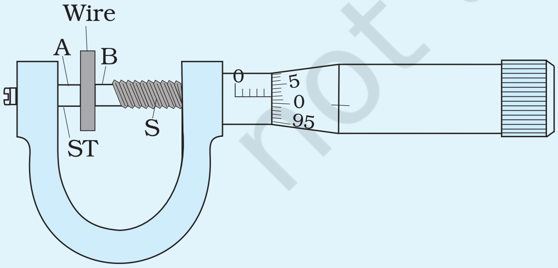


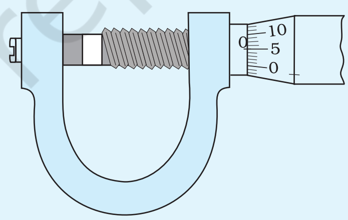

***Fig.E 2.5:*** *Measuring thickness with a screw guage*

## ZERO ERROR

When the end of the screw and the surface of the stud are in contact with each other, the linear scale and the circular scale reading should be zero. In case this is not so, the screw gauge is said to have an error called zero error.

Fig. E 2.3 shows an enlarged view of a screw gauge with its faces A and B in contact. Here, the zero mark of the LS and the CS are coinciding with each other.

When the reading on the circular scale across the linear scale is more than zero (or positive), the instrument has **Positive zero error** as shown in Fig. E 2.4 (a). When the reading of the circular scale across the linear scale is less than zero (or negative), the instrument is said to have **negative zero error** as shown in Fig. E 2.4 (b).




(b)

***Fig.E 2.4 (b):*** *Showing a negative zero error*

## TAKING THE LINEAR SCALE READING

The mark on the linear scale which lies close to the left edge of the circular scale is the linear scale reading. For example, the linear scale reading as shown in Fig. E 2.5, is 0.5 cm.

## TAKING CIRCULAR SCALE READING

The division of circular scale which coincides with the main scale line is the reading of circular scale. For example, in the Fig. E 2.5, the circular scale reading is 2.

**TOTAL READING**

Total reading

= linear scale reading + circular scale reading × least count

= 0.5 + 2 × 0.001

= 0.502 cm

## PRINCIPLE

The linear distance moved by the screw is directly proportional to the rotation given to it. The linear distance moved by the screw when it is rotated by one division of the circular scale, is the least distance that can be measured accurately by the instrument. It is called the least count of the instrument.

$$\text{Least count} = \frac{\text{pitch}}{\text{No. of divisions on circular scale}}$$

For example for a screw gauge with a pitch of 1mm and 100 divisions on the circular scale. The least count is

$$1\ \text{mm}/100 = 0.01\ \text{mm}$$

This is the smallest length one can measure with this screw gauge.

In another type of screw gauge, pitch is 0.5 mm and there are 50 divisions on the circular scale. The least count of this screw gauge is 0.5 mm/50 = 0.01 mm. Note that here two rotations of the circular scale make the screw to advance through a distance of 1 mm. Some screw gauge have a least count of 0.001 mm (i.e. $10^{-6}$ m) and therefore are called micrometer screw.

**(a) Measurement of Diameter of a Given Wire**

## PROCEDURE

1. Take the screw gauge and make sure that the rachet R on the head of the screw functions properly.
2. Rotate the screw through, say, ten complete rotations and observe the distance through which it has receded. This distance is the reading on the linear scale marked by the edge of the circular scale. Then, find the pitch of the screw, i.e., the distance moved by the screw in one complete rotation. If there are n divisions on the circular scale, then distance moved by the screw when it is rotated through one division on the circular scale is called the least count of the screw gauge, that is,

$$\text{Least count} = \frac{\text{pitch}}{n}$$

3. Insert the given wire between the screw and the stud of the screw gauge. Move the screw forward by rotating the rachet till the wire is gently gripped between the screw and the stud as shown in Fig. E 2.5. Stop rotating the rachet the moment you hear a click sound.
4. Take the readings on the linear scale and the circular scale.
5. From these two readings, obtain the diameter of the wire.

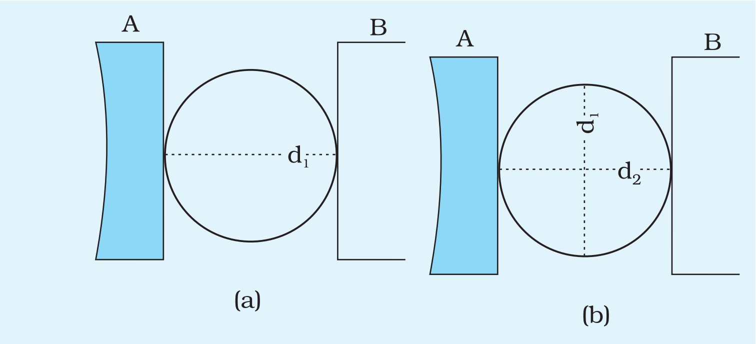



***Fig.E 2.6 (a):*** *Two magnified views (a) and (b) of a wire showing its perpendicular diameters $d_1$ and $d_2$. $d_2$ is obtained after the rotating the wire in the clockwise direction through 90°.*

6. The wire may not have an exactly circular cross-section. Therefore. it is necessary to measure the diameter of the wire for two positions at right angles to each other. For this, first record the reading of diameter $d_1$ [Fig. E 2.6 (a)] and then rotate the wire through 90° at the same cross-sectional position. Record the reading for diameter $d_2$ in this position [Fig. E 2.6 (b)].
7. The wire may not be truly cylindrical. Therefore, it is necessary to measure the diameter at several different places and obtain the average value of diameter. For this, repeat the steps (3) to (6) for three more positions of the wire.
8. Take the mean of the different values of diameter so obtained.
9. Substract zero error, if any, with proper sign to get the corrected value for the diameter of the wire.

## OBSERVATIONS AND CALCULATION

The length of the smallest division on the linear scale = ... mm

Distance moved by the screw when it is rotated through $x$ complete rotations, $y$ = ... mm

Pitch of the screw = $\dfrac{y}{x}$ = ... mm

Number of divisions on the circular scale $n$ = ...

Least Count (L.C.) of screw guage

$$= \frac{pitch}{No.\ of\ divisions\ on\ the\ circular\ scale} = \ldots \text{ mm}$$

Zero error with sign (No. of div. × L. C.) = ... mm

**Table E 2.1: Measurement of the diameter of the wire**

| S. No. | Reading along one direction ($d_1$) | | | Reading along perpendicular direction ($d_2$) | | | Measured diameter $d = \frac{d_1 + d_2}{2}$ |
|---|---|---|---|---|---|---|---|
| | Linear scale reading $M$ (mm) | Circular scale reading ($n$) | Diameter $d_1 = M + n \times$ L.C. (mm) | Linear scale reading $M$ (mm) | Circular scale reading ($n$) | Diameter $d_2 = M + n \times$ L.C. (mm) | (mm) |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |

Mean diameter = ... mm

Mean corrected value of diameter

= measured diameter – (zero error with sign) = ... mm

## RESULT

The diameter of the given wire as measured by screw gauge is ... mm

## PRECAUTIONS

1. Rachet arrangement in screw gauge must be utilised to avoid undue pressure on the wire as this may change the diameter.
2. Move the screw in one direction else the screw may develop "play".
3. Screw should move freely without friction.
4. Reading should be taken atleast at four different points along the length of the wire.
5. View all the reading keeping the eye perpendicular to the scale to avoid error due to parallax.

## SOURCES OF ERROR

1. The wire may not be of uniform cross-section.
2. Error due to backlash though can be minimised but cannot be completely eliminated.

### BACKLASH ERROR

In a good instrument (either screw gauge or a spherometer) the thread on the screw and that on the nut (in which the screw moves), should tightly fit with each other. However, with repeated use, the threads of both the screw and the nut may get worn out. As a result a gap develops between these two threads, which is called "play". The play in the threads may introduce an error in measurement in devices like screw gauge. This error is called backlash error. In instruments having backlash error, the screw slips a small linear distance without rotation. To prevent this, it is advised that the screw should be moved in only one direction while taking measurements.

3. The divisions on the linear scale and the circular scale may not be evenly spaced.

## DISCUSSION

1. Try to assess if the value of diameter obtained by you is realistic or not. There may be an error by a factor of 10 or 100 . You can obtain a very rough estimation of the diameter of the wire by measuring its thickness with an ordinary metre scale.
2. Why does a screw gauge develop backlash error with use?

## SELF ASSESSMENT

1. Is the screw gauge with smaller least count always better? If you are given two screw gauges, one with 100 divisions on circular scale and another with 200 divisions, which one would you prefer and why?
2. Is there a situation in which the linear distance moved by the screw is not proportional to the rotation given to it?
3. Is it possible that the zero of circular scale lies above the zero line of main scale, yet the error is positive zero error?
4. For measurement of small lengths, why do we prefer screw gauge over Vernier Callipers?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Think of a method to find the 'pitch' of bottle caps.
2. Compare the 'pitch' of an ordinary screw with that of a screw guage. In what ways are the two different?
3. Measure the diameters of petioles (stem which holds the leaf) of different leaf and check if it has any relation with the mass or surface area of the leaf. Let the petiole dry before measuring its diameter by screw gauge.

4. Measure the thickness of the sheet of stainless steel glasses of various make and relate it to their price structure.
5. Measure the pitch of the 'screw' end of different types of hooks and check if it has any relation with the weight each one of these hooks are expected to hold.
6. Measure the thickness of different glass bangles available in the Market. Are they made as per some standard?
7. Collect from the market, wires of different gauge numbers, measure their diameters and relate the two. Find out various uses of wires of each gauge number.

### (b) Measurement of Thickness of a Given Sheet

## PROCEDURE

1. Insert the given sheet between the studs of the screw gauge and determine the thickness at five different positions.
2. Find the average thickness and calculate the correct thickness by applying zero error following the steps followed earlier.

## OBSERVATIONS AND CALCULATION

Least count of screw gauge = ... mm

Zero error of screw gauge = ... mm

**Table E 2.2 Measurement of thickness of sheet**

| S. No. | Linear scale reading $M$ (mm) | Circular scale reading $n$ | Thickness $t = M + n \times$ L.C. (mm) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

Mean thickness of the given sheet = ... mm

Mean corrected thickness of the given sheet

= observed mean thickness – (zero error with sign) = ... mm

## RESULT

The thickness of the given sheet is ... m.

## SOURCES OF ERROR

1. The sheet may not be of uniform thickness.
2. Error due to backlash though can be minimised but cannot be eliminated completely.

## DISCUSSION

1. Assess whether the thickness of sheet measured by you is realistic or not. You may take a pile of say 20 sheets, and find its thickness using a metre scale and then calculate the thickness of one sheet.
2. What are the limitations of the screw gauge if it is used to measure the thickness of a thick cardboard sheet?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Find out the thickness of different wood ply boards available in the market and verify them with the specifications provided by the supplier.
2. Measure the thickness of the steel sheets used in steel almirahs manufactured by different suppliers and compare their prices. Is it better to pay for a steel almirah by mass or by the guage of steel sheets used?
3. Design a cardboard box for packing 144 sheets of paper and give its dimensions.
4. Hold 30 pages of your practical notebook between the screw and the stud and measure its thickness to find the thickness of one sheet.
5. Find the thickness of plastic ruler/metal sheet of the geometry box.

### (C) Determination of Volume of the Given Irregular Lamina

## PROCEDURE

1. Find the thickness of lamina as in Experiment E 2(b).
2. Place the irregular lamina on a sheet of paper with mm graph. Draw the outline of the lamina using a sharp pencil. Count the total number of squares and also more than half squares within the boundary of the lamina and determine the area of the lamina.
3. Obtain the volume of the lamina using the relation mean thickness × area of lamina.

## OBSERVATIONS AND CALCULATION

Same as in Experiment E 2(b). The first section of the table is now for readings of thickness at five different places along the edge of the

lamina. Calculate the mean thickness and make correction for zero error, if any.

From the outline drawn on the graph paper:-

Total number of complete squares = … $mm^2$ = … $cm^2$

Volume of the lamina = … $mm^3$ = … $cm^3$

## RESULT

Volume of the given lamina = … $cm^3$

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Find the density of cardboard.
2. Find the volume of a leaf (neem, bryophyte).
3. Find the volume of a cylindrical pencil.

# EXPERIMENT 3

## AIM

To determine the radius of curvature of a given spherical surface by a spherometer.

## APPARATUS AND MATERIAL REQUIRED

A spherometer, a spherical surface such as a watch glass or a convex mirror and a plane glass plate of about 6 cm × 6 cm size.

## DESCRIPTION OF APPARATUS

A spherometer consists of a metallic triangular frame F supported on three legs of equal length A, B and C (Fig. E 3.1). The lower tips of the legs form three corners of an equilateral triangle ABC and lie on the periphery of a base circle of known radius, *r*. The spherometer also consists of a central leg OS (an accurately cut screw), which can be raised or lowered through a threaded hole V (nut) at the centre of the frame F. The lower tip of the central screw, when lowered to the plane (formed by the tips of legs A, B and C) touches the centre of triangle ABC. The central screw also carries a circular disc D at its top having a circular scale divided into 100 or 200 equal parts. A small vertical scale P marked in millimetres or half-millimetres, called main scale is also fixed parallel to the central screw, at one end of the frame F. This scale P is kept very close to the rim of disc D but it does not touch the disc D. This scale reads the vertical distance which the central leg moves through the hole V. This scale is also known as pitch scale.

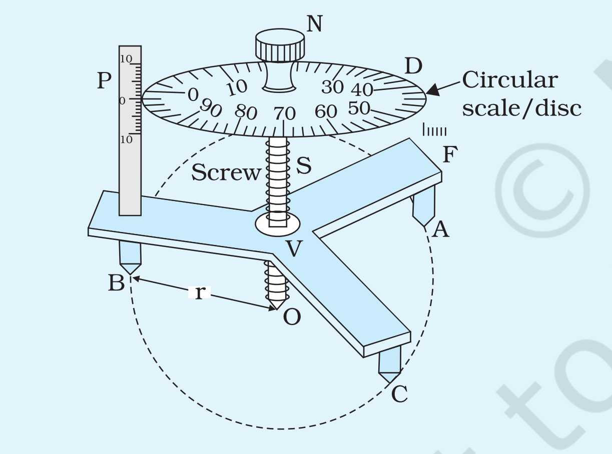



***Fig. E 3.1:*** *A spherometer*

## TERMS AND DEFINITIONS

**Pitch:** It is the vertical distance moved by the central screw in one complete rotation of the circular disc scale.

Commonly used spherometers in school laboratories have graduations in millimetres on pitch scale and may have100 equal divisions on circular disc scale. In one rotation of the circular scale, the central screw advances or recedes by 1 mm. Thus, the pitch of the screw is 1 mm.

**Least Count:** Least count of a spherometer is the distance moved by the spherometer screw when it is turned through one division on the circular scale, *i.e.*,

$$\text{Least count of the spherometer} = \frac{\text{Pitch of the spherometer screw}}{\text{Number of divisions on the circular scale}}$$

The least count of commonly used spherometers is 0.01 mm. However, some spherometers have least count as small as 0.005 mm or 0.001 mm.

## PRINCIPLE

### FORMULA FOR THE RADIUS OF CURVATURE OF A SPHERICAL SURFACE

Let the circle AOBXZY (Fig. E 3.2) represent the vertical section of sphere of radius R with E as its centre (The given spherical surface is a part of this sphere). Length OZ is the diameter (= 2*R*) of this vertical section, which bisects the chord AB. Points A and B are the positions of the two spherometer legs on the given spherical surface. The position of the third spherometer leg is not shown in Fig. E 3.2. The point O is the point of contact of the tip of central screw with the spherical surface.

Fig. E 3.3 shows the base circle and equilateral triangle ABC formed by the tips of the three spherometer legs. From this figure, it can be noted that the point M is not only the mid point of line AB but it is the centre of base circle and centre of the equilateral triangle ABC formed by the lower tips of the legs of the spherometer (Fig. E 3.1).

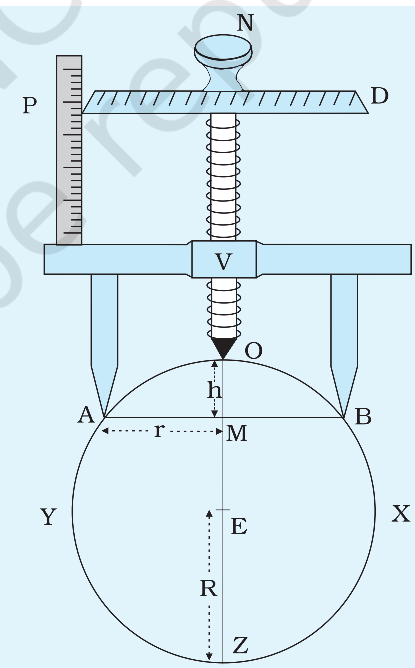



***Fig. E 3.2:** Measurement of radius of curvature of a spherical surface*

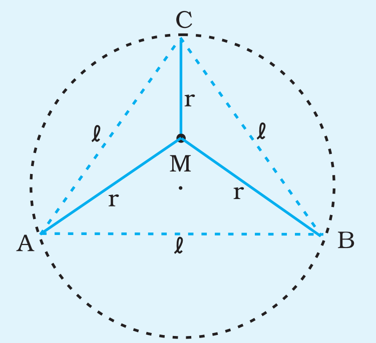



***Fig. E 3.3:** The base circle of the spherometer*

In Fig. E 3.2 the distance OM is the height of central screw above the plane of the circular section ABC when its lower

tip just touches the spherical surface. This distance OM is also called sagitta. Let this be $h$. It is known that if two chords of a circle, such as AB and OZ, intersect at a point M then the areas of the rectangles described by the two parts of chords are equal. Then

$$AM.MB = OM.MZ$$

$$(AM)^2 = OM\ (OZ - OM) \text{ as } AM = MB$$

Let EZ (= OZ/2) = $R$, the radius of curvature of the given spherical surface and AM = $r$, the radius of base circle of the spherometer.

$$r^2 = h\,(2R - h)$$

Thus,
$$R = \frac{r^2}{2h} + \frac{h}{2}$$

Now, let $l$ be the distance between any two legs of the spherometer or the side of the equilateral triangle ABC (Fig. E 3.3), then from geometry we have

Thus, $r = \frac{l}{\sqrt{3}}$, the radius of curvature ($R$) of the given spherical surface can be given by

$$R = \frac{l^2}{6h} + \frac{h}{2}$$

## PROCEDURE

1. Note the value of one division on pitch scale of the given spherometer.
2. Note the number of divisions on circular scale.
3. Determine the pitch and least count (L.C.) of the spherometer. Place the given flat glass plate on a horizontal plane and keep the spherometer on it so that its three legs rest on the plate.
4. Place the spherometer on a sheet of paper (or on a page in practical note book) and press it lightly and take the impressions of the tips of its three legs. Join the three impressions to make an equilateral triangle ABC and measure all the sides of ΔABC. Calculate the mean distance between two spherometer legs, $l$.

   In the determination of radius of curvature $R$ of the given spherical surface, the term $l^2$ is used (see formula used). Therefore, great care must be taken in the measurement of length, $l$.

5. Place the given spherical surface on the plane glass plate and then place the spherometer on it by raising or lowering the central screw sufficiently upwards or downwards so that the three spherometer legs may rest on the spherical surface (Fig. E 3.4).

6. Rotate the central screw till it gently touches the spherical surface. To be sure that the screw touches the surface one can observe its image formed due to reflection from the surface beneath it.

7. Take the spherometer reading $h_1$ by taking the reading of the pitch scale. Also read the divisions of the circular scale that is in line with the pitch scale. Record the readings in Table E 3.1.

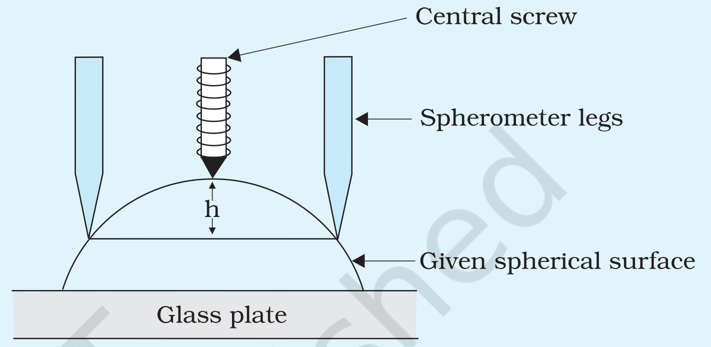



***Fig.E 3.4:*** *Measurement of sagitta h*

8. Remove the spherical surface and place the spherometer on plane glass plate. Turn the central screw till its tip gently touches the glass plate. Take the spherometer reading $h_2$ and record it in Table E 3.1. The difference between $h_1$ and $h_2$ is equal to the value of sagitta ($h$).

9. Repeat steps (5) to (8) three more times by rotating the spherical surface leaving its centre undisturbed. Find the mean value of $h$.

## OBSERVATIONS

A. Pitch of the screw:

(i) Value of smallest division on the vertical pitch scale = ... mm

(ii) Distance $q$ moved by the screw for $p$ complete rotations of the circular disc = ... mm

(iii) Pitch of the screw $(= q/p)$ = ... mm

B. Least Count ($L.C.$) of the spherometer:

(i) Total no. of divisions on the circular scale ($N$) = ...

(ii) Least count (L.C.) of the spherometer

$$= \frac{\text{Pitch of the spherometer screw}}{\text{Number of divisions on the circular scale}}$$

$$\text{L.C.} = \frac{\text{Pitch of the screw}}{N} = \dots \text{ cm}$$

C. Determination of length $l$ (from equilateral triangle ABC)

(i) Distance AB = ... cm

(ii) Distance BC = ... cm

(iii) Distance CA = ... cm

$$\text{Mean } l = \frac{AB + BC + CA}{3} = \ldots \text{ cm}$$

**Table E 3.1 Measurement of sagitta *h***

| S. No. | Spherometer readings | | | | | | | | $(h_1 - h_2)$ |
|---|---|---|---|---|---|---|---|---|---|
| | With Spherical Surface | | | | Horizontal Plane Surface | | | | |
| | Pitch Scale reading $x$ (cm) | Circular scale division coinciding with pitch scale $y$ | Circular scale reading $z = y \times$ L.C (cm) | Spherometer reading with spherical surface $h_1 = x + z$ (cm) | Pitch Scale reading $x'$ (cm) | Circular scale division coinciding with pitch scale $y'$ | Circular scale reading $z' = y \times$ L.C. (cm) | Spherometer reading with spherical surface $h_2 = x' + z'$ (cm) | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Mean $h$ = ... cm

## CALCULATIONS

A. Using the values of $l$ and $h$, calculate the radius of curvature R from the formula:

$$R = \frac{l^2}{6h} + \frac{h}{2};$$

the term $h/2$ may safely be dropped in case of surfaces of large radii of curvature (In this situation error in $\left(\frac{l^2}{6h}\right)$ is of the order of $h/2$).

## RESULT

The radius of curvature R of the given spherical surface is ... cm.

## PRECAUTIONS

1. The screw may have friction.
2. Spherometer may have backlash error.

## SOURCES OF ERROR

1. Parallax error while reading the pitch scale corresponding to the level of the circular scale.
2. Backlash error of the spherometer.
3. Non-uniformity of the divisions in the circular scale.
4. While setting the spherometer, screw may or may not be touching the horizontal plane surface or the spherical surface.

## DISCUSSION

Does a given object, say concave mirror or a convex mirror, have the same radius of curvature for its two surfaces? [**Hint:** Does the thickness of the material of object make any difference?]

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the focal length of a convex/concave spherical mirror using a spherometer.
2. (a) Using spherometer measure the thickness of a small piece of thin sheet of metal/glass.

   (b) Which instrument would be precise for measuring thickness of a card sheet – a screw gauge or a spherometer?

# EXPERIMENT 4

## AIM

To determine mass of two different objects using a beam balance.

## APPARATUS AND MATERIAL REQUIRED

Physical balance, weight box with a set of milligram masses and forceps, spirit level and two objects whose masses are to be determined.

## DESCRIPTION OF PHYSICAL BALANCE

A physical balance is a device that measures the weight (or gravitational mass) of an object by comparing it with a standard weight (or standard gravitational mass).

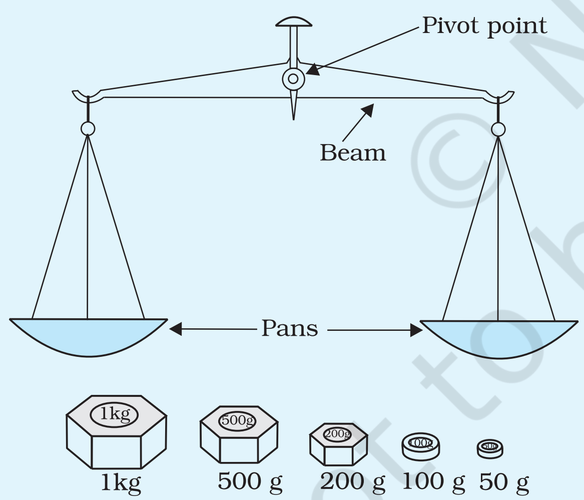



***Fig. E 4.1:*** *A beam balance and set of weights*

The most commonly used two-pan beam balance is an application of a **lever**. It consists of a rigid uniform bar (beam), two pans suspended from each end, and a pivotal point in the centre of the bar (Fig. E 4.1). At this pivotal point, a support (called *fulcrum*) is set at right angles to the beam. This beam balance works on the principle of moments.

For high precision measurements, a physical balance (Fig. E 4.2) is often used in laboratories. Like a common beam balance, a physical balance too consists of a pair of scale pans $P_1$ and $P_2$, one at each end of a rigid beam B. The pans $P_1$ and $P_2$ are suspended through stirrups $S_1$ and $S_2$ respectively, on inverted knife-edges $E_1$ and $E_2$, respectively, provided symmetrically near the end of the beam B. The beam is also provided with a hard material (like agate) knife-edge (E) fixed at the centre pointing downwards and is supported on a vertical pillar (V) fixed on a wooden baseboard (W). The baseboard is provided with three levelling screws $W_1$, $W_2$ and $W_3$. In most balances, screws $W_1$ and $W_2$ are of adjustable heights and through these the baseboard W is levelled horizontally. The third screw $W_3$, not visible in Fig. E 4.2, is not of adjustable height and is fixed in the middle at the back of board W. When the balance is in use, the

knife-edge E rests on a plane horizontal plate fixed at the top of pillar V. Thus, the central edge E acts as a *pivot* or *fulcrum* for the beam B. When the balance is not in use, the beam rests on the supports $X_1$ and $X_2$. These supports, $X_1$ and $X_2$, are fixed to another horizontal bar attached with the central pillar V. Also, the pans $P_1$ and $P_2$ rest on supports $A_1$ and $A_2$, respectively, fixed on the wooden baseboard. In some balances, supports $A_1$ and $A_2$ are not fixed and in that case the pans rest on board W, when the balance is not in use.

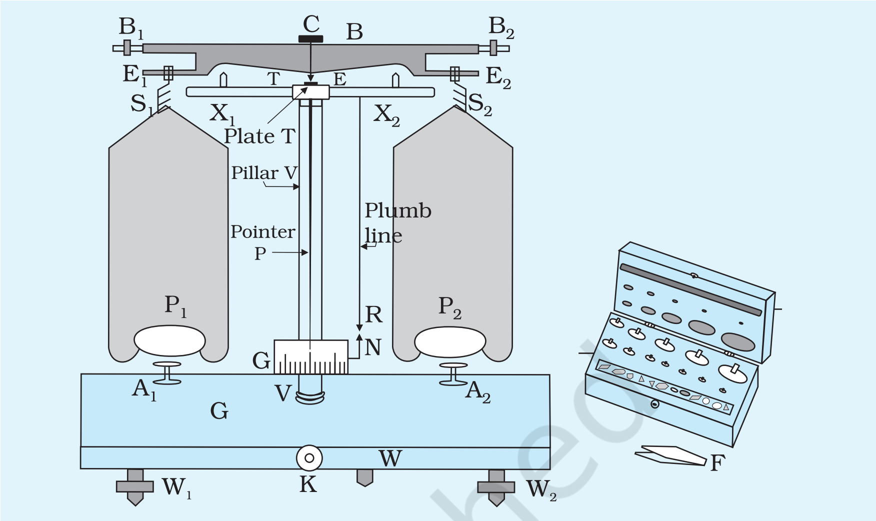



***Fig. E 4.2:*** *A physical balance and a weight box*

At the centre of beam B, a pointer P is also fixed at right angles to it. A knob K, connected by a horizontal rod to the vertical pillar V, is also attached from outside with the board W. With the help of this knob, the vertical pillar V and supports $A_1$ and $A_2$ can be raised or lowered simultaneously. Thus, at the 'ON' position of the knob K, the beam B also gets raised and is then suspended only by the knife-edge E and oscillates freely. Along with the beam, the pans $P_1$ and $P_2$ also begin to swing up and down. This oscillatory motion of the beam can be observed by the motion of the pointer P with reference to a scale (G) provided at the base of the pillar V. When the knob K is turned back to 'OFF' position, the beam rests on supports $X_1$ and $X_2$ keeping the knife-edge E and plate T slightly separated; and the pans $P_1$ and $P_2$ rest on supports $A_1$ and $A_2$ respectively. In the 'OFF' position of the knob K, the entire balance is said to be *arrested*. Such an arresting arrangement protects the knife-edges from undue wear and tear and injury during transfer of masses (unknown and standards) from the pan.

On turning the knob K slowly to its 'ON' position, when there are no masses in the two pans, the oscillatory motion (or swing) of the pointer P with reference to the scale G must be same on either side of the zero mark on G. And the pointer must stop its oscillatory motion at the zero mark. It represents the vertical position of the pointer P and horizontal position of the beam B. However, if the swing is not the same on either side of the zero mark, the two balancing screws $B_1$ and $B_2$ at the two ends of the beam are adjusted. The baseboard W is levelled horizontal1y to make the pillar V vertical.

This setting is checked with the help of plumb line (R) suspended by the side of pillar V. The appartus is placed in a glass case with two doors.

For measuring the gravitational mass of an object using a physical balance, it is compared with a standard mass. A set of standard masses (100 g, 50 g, 20 g, 10g, 5 g, 2 g, and 1 g) along with a pair of forceps is contained in a wooden box called *Weight Box.* The masses are arranged in circular grooves as shown in Fig. E 4.2. A set of milligram masses (500 mg, 200 mg, 100 mg, 50 mg, 20 mg 10 mg, 5 mg, 2 mg, and 1 mg) is also kept separately in the weight box. A physical balance is usually designed to measure masses of bodies up to 250 g.

## PRINCIPLE

The working of a physical balance is based on the principle of moments. In a balance, the two arms are of equal length and the two pans are also of equal masses. When the pans are empty, the beam remains horizontal on raising the beam base by using the lower knob. When an object to be weighed is placed in the left pan, the beam turns in the anticlockwise direction. Equilibrium can be obtained by placing suitable known standard weights on the right hand pan. Since, the force arms are equal, the weight (i.e., forces) on the two pans have to be equal.

A physical balance compares forces. The forces are the weights (mass × acceleration due to gravity) of the objects placed in the two pans of the physical balance. Since the weights are directly proportional to the masses if weighed at the same place, therefore, a physical balance is used for the comparison of gravitational masses. Thus, if an object O having gravitational mass $m$ is placed in one pan of the physical balance and a standard mass O′ of known gravitational mass $m_s$ is put in the other pan to keep the beam the horizontal, then

Weight of body O in one pan = Weight of body O′ in other pan

Or, $$mg = m_s g$$

where $g$ is the acceleration due to gravity, which is constant. Thus,

$$m = m_s$$

That is,

the mass of object O in one pan = standard mass in the other pan

## PROCEDURE

1. Examine the physical balance and recognise all of its parts. Check that every part is at its proper place.

2. Check that set of the weight, both in gram and milligram, in the weight box are complete.
3. Ensure that the pans are clean and dry.
4. Check the functioning of arresting mechanism of the beam B by means of the knob K.
5. Level the wooden baseboard W of the physical balance horizontally with the help of the levelling screws $W_1$ and $W_2$. In levelled position, the lower tip of the plumb line R should be exactly above the fixed needle point N. Use a spirit level for this purpose.
6. Close the shutters of the glass case provided for covering the balance and slowly raise the beam B using the knob K.
7. Observe the oscillatory motion of the pointer P with reference to the small scale G fixed at the foot of the vertical pillar V. In case, the pointer does not start swinging, give a small gentle jerk to one of the pans. Fix your eye perpendicular to the scale to avoid parallax. **Caution:** Do not touch the pointer.
8. See the position of the pointer P. Check that it either stops at the central zero mark or moves equally on both sides of the central zero mark on scale G. If not, adjust the two balancing screws $B_1$ and $B_2$ placed at the two ends of the beam B so that the pointer swings equally on either side of the central zero mark or stops at the central zero mark. **Caution**: *Arrest the balance before adjusting the balancing screws.*
9. Open the shutter of the glass case of the balance. Put the object whose mass *(M)* is to be measured in the left hand pan and add a suitable standard mass say $M_1$, (which may be more than the rough estimate of the mass of the object) in the right hand pan of the balance in **its rest (or arrested) position**, *i.e.*, when the beam B is lowered and allowed to rest on stoppers $X_1$ and $X_2$. Always use forceps for taking out the standard mass from the weight box and for putting them back.

   The choice of putting object on left hand pan and standard masses on right hand pan is arbitrary and chosen due to the ease in handling the standard masses. A left handed person may prefer to keep the object on right hand pan and standard masses on left hand pan. It is also advised to keep the weight box near the end of board W on the side of the pan being used for putting the standard masses.
10. Using the knob K, gently raise the beam (now the beam's knife edge E will rest on plate T fixed on the top of the pillar V) and observe the motion of the pointer P. It might rest on one side of

the scale or might oscillate more in one direction with reference to the central zero mark on the scale G.

**Note:** Pans should not swing while taking the observations. The swinging of pans may be stopped by carefully touching the pan with the finger in the arresting position of the balance.

11. Check whether $M_1$ is more than $M$ or less. For this purpose, the beam need to be raised to the full extent.

12. Arrest the physical balance. Using forceps, replace the standard masses kept in the right pan by another mass (say $M_2$). It should be lighter if $M_1$ is more than the mass $M$ and vice versa.

13. Raise the beam and observe the motion of the pointer P and check whether the standard mass kept on right hand pan is still heavier (or lighter) than the mass $M$ so that the pointer oscillates more in one direction. If so, repeat step 12 using standard masses in gram till the pointer swings **nearly equal** on both sides of the central zero mark on scale G. Make the standard masses kept on right hand pan to be *slightly lesser* than the mass of object. This would result in the measurement of mass $M$ of object with a precision of 1 g. Lower the beam B.

14. For **fine measurement** of mass add extra milligram masses in the right hand pan in descending order until the pointer swings nearly equal number of divisions on either side of the central zero mark on scale G (use forceps to pick the milligram or fractional masses by their turned-up edge). In the equilibrium position (*i.e.*, when the masses kept on both the pans are equal), the pointer will rest at the centre zero mark. Close the door of the glass cover to prevent disturbances due to air draughts.

**Note:** The beam B of the balance should not be raised to the full extent until milligram masses are being added or removed. Pointer's position can be seen by lifting the beam very gently and for a short moment.

15. Arrest the balance and take out masses from the right hand pan one by one and note total mass in notebook. Replace them in their proper slot in the weight box. Also remove the object from the left hand pan.

16. Repeat the step 9 to step 15 two more times for the same object.

17. Repeat steps 9 to 15 and determine the mass of the second given object.

Record the observations for the second object in the table similar to Table E 4.1.

## OBSERVATIONS

**TABLE E 4.1: Mass of First Object**

| S. No. | Standard mass | | Mass of the object ($x + y$) |
|---|---|---|---|
| | Gram weights, $x$ | Milligram weights, $y$ | |
| | (g) | (mg) | (g) |
| 1 | | | |
| 2 | | | |
| 3 | | | |

Mean mass of the first object = ... g

**TABLE E 4.2: Mass of Second Object**

| S. No. | Standard mass | | Mass of the object ($x + y$) |
|---|---|---|---|
| | Gram weights, $x$ | Milligram weights, $y$ | |
| | (g) | (mg) | (g) |
| 1 | | | |
| 2 | | | |
| 3 | | | |

Mean mass of the second object = ... g

## RESULT

The mass of the first given object is ... g and that of the second object is ... g.

## PRECAUTIONS

1. The correctness of mass determined by a physical balance depends on minimising the errors, which may arise due to the friction between the knife-edge E and plate T. Friction cannot be removed completely. However, it can be minimised when the knife-edge is sharp and plate is smooth. The friction between other parts of the balance may be minimised by keeping all the parts of balance dry and clean.
2. Masses should always be added in the descending order of magnitude. Masses should be placed in the centre of the pan.
3. The balance should not be loaded with masses more than capacity. Usually a physical balance is designed to measure masses upto 250 g.

4. Weighing of hot and cold bodies using a physical balance should be avoided. Similarly, active substances like chemicals, liquids and powders should *not* be kept directly on the pan.

## SOURCES OF ERROR

1. There is always some error due to friction at various parts of the balance.

2. The accuracy of the physical balance is 1 mg. This limits the possible instrumental error.

## DISCUSSION

The deviation of experimental value from the given value may be due to many factors.

1. The forceps used to load/unload the weights might contain dust particles sticking to it which may get transferred to the weight.

2. Often there is a general tendancy to avoid use of levelling and balancing screws to level the beam/physical balance just before using it.

## SELF ASSESSMENT

1. Why is it necessary to close the shutters of the glass case for an accurate measurement?

2. There are two physical balances: one with equal arms and other with unequal arms. Which one should be preferred? What additional steps do you need to take to use a physical balance with unequal arms.

3. The minimum mass that can be used from the weight box is 10 g. Find the possible instrumental error.

4. Instead of placing the mass (say a steel block) on the pan, suppose it is hanged from the same hook $S_1$ on which the pan $P_1$ is hanging. Will the value of measured mass be same or different?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Determination of density of material of a non-porous block and verification of Archimedes principle:

   **Hint**: First hang the small block (say steel block) from hook $S_1$ and determine its mass in air. Now put the hanging block in a half water-filled measuring cylinder. Measure the mass of block in water. Will it be same, more or less? Also detemine the volume of steel block. Find the density of the material of the block. From the measured masses of the steel block in air and water, verify Archimedes principle.

# EXPERIMENT 5

## AIM

Measurement of the weight of a given body (a wooden block) using the parallelogram law of vector addition.

## APPARATUS AND MATERIAL REQUIRED

The given body with hook, the parallelogram law of vector apparatus (Gravesand's apparatus), strong thread, slotted weights (two sets), white paper, thin mirror strip, sharp pencil.

## DESCRIPTION OF MATERIAL

***Gravesand's apparatus:*** It consists of a wooden board fixed vertically on two wooden pillars as shown in Fig. E 5.1 (a). Two pulleys $P_1$ and $P_2$ are provided on its two sides near the upper edge of the board. A thread carrying hangers for addition of slotted weights is made to pass over the pulleys so that two forces P and Q can be applied by adding weights in the hangers. By suspending the given object, whose weight is to be determined, in the middle of the thread, a third force X is applied.



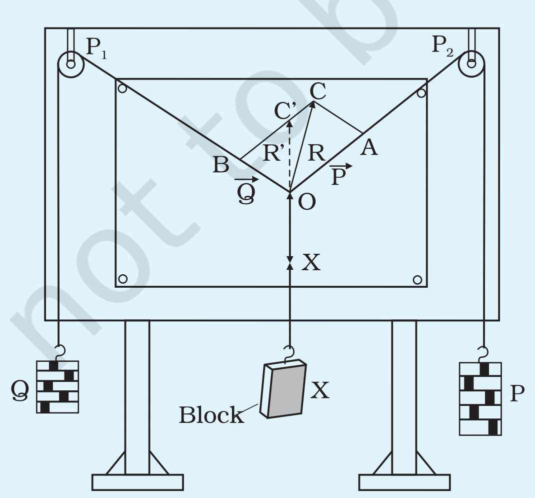



***Fig. E 5.1(a):*** *Gravesand's apparatus*

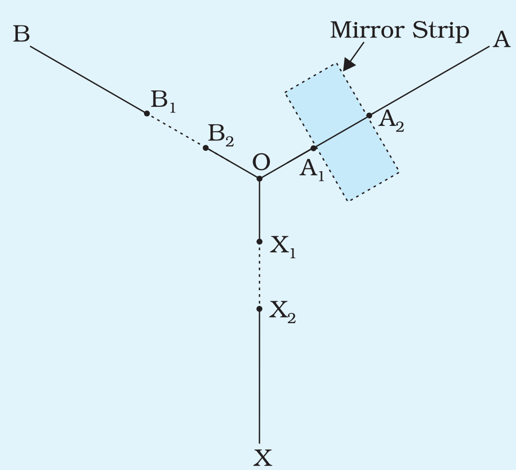



***Fig. E 5.1(b):*** *Marking forces to scale*

## PRINCIPLE

Working of this apparatus is based on the parallelogram law of vector addition. The law states that "when two forces act simultaneously at a point and are represented in magnitude and direction by the two adjacent sides of a parallelogram, then the resultant of forces can be represented both in magnitude and direction by the diagonal of the parallelogram passing through the point of application of the two forces.

Let $P$ and $Q$ be the magnitudes of the two forces and $\theta$ the angle between them. Then the resultant $R$ of $P$ and $Q$ is given by

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

If two known forces $P$ and $Q$ and a third unknown force due to the weight of the given body are made to act at a point O [Fig. 5.1 (a)] such that they are in equilibrium, the unknown force is equal to the resultant of the two forces. Thus, the weight of a given body can be found.

## PROCEDURE

1. Set the board of Gravesand's apparatus in vertical position by using a plumb-line. **Ensure that the pulleys are moving smoothly**. Fix a sheet of white paper on the wooden board with drawing pins.
2. Take a sufficiently long piece of string and tie the two hangers at its ends. Tie another shorter string in the middle of the first string to make a knot at 'O'. Tie the body of unknown weight at the other end of the string. Arrange them on the pulley as shown in Fig. E 5.1 (a) with slotted weights on the hangers.
3. Add weights in the hangers such that the junction of the threads is in equilibrium in the lower half of the paper. **Make sure that neither the weights nor the threads touch the board or the table**.
4. Bring the knot of the three threads to position of no-friction. For this, first bring the knot to a point rather wide off its position of no-friction. On leaving there, it moves towards the position of no-friction because it is not in equilibrium. While it so moves, tap the board gently. The point where the knot thus come to rest is taken as the position of no-friction, mark this point. Repeat the procedure several times. Each time let the knot approach the position of no-friction from a different direction and mark the point where it comes to rest. Find by judgement the centre of those points which are close together. Mark this centre as O.

5. To mark the direction of the force acting along a string, place a mirror strip below the string on the paper . Adjust the position of the eye such that there is no parallax between the string and its image. Mark the two points $A_1$ and $A_2$ at the edges of the mirror where the image of the string leaves the mirror [Fig E 5.1 (b)].

   Similarly, mark the directions of other two forces by points $B_1$ and $B_2$ and by points $X_1$ and $X_2$ along the strings OB and OX respectively.

6. Remove the hangers and note the weight of each hanger and slotted weights on them.

7. Place the board flat on the table with paper on it. Join the three pairs of points marked on the paper and extend these lines to meet at O. These three lines represent the directions of the three forces.

8. Choose a suitable scale, say 0.5 N (50 g wt) = 1cm and cut off length OA and OB to represent forces *P* and *Q* respectively acting at point O. With OA and OB as adjacent sides, complete the parallelogram OACB. Ensure that the scale chosen is such that the parallelogram covers the maximum area of the sheet.

9. Join points O and C. The length of OC will measure the weight of the given body. See whether OC is along the straight line XO. If not, let it meet BC at some point C′ . Measure the angle COC′ .

10. Repeat the steps 1 to 9 by suspending two different sets of weights and calculate the mean value of the unknown weight.

## OBSERVATIONS

Weight of each hanger = ... N

Scale, 1cm = ... N

**Table E 5.1: Measurement of weight of given body**

| S. No. | Force *P* = *wt* of (hanger + slotted weight) | | Force *Q* = *wt* of (hanger + slotted weight | | Length OC = *L* | Unknown weight *X* = *L* × *s* | Angle COC′ |
|---|---|---|---|---|---|---|---|
| | P (N) | OA (cm) | Q (N) | OB (cm) | (cm) | (N) | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |

## RESULT

The weight of the given body is found to be ... N.

## PRECAUTIONS

1. Board of Gravesand's apparatus is perpendicular to table on which it is placed, by its construction. Check up by plumb line that it is vertical. If it is not, make table top horizontal by putting packing below appropriate legs of table.

2. Take care that pulleys are free to rotate, i.e., have little friction between pulley and its axle.

## SOURCES OF ERROR

1. Friction at the pulleys may persist even after oiling.

2. Slotted weights may not be accurate.

3. Slight inaccuracy may creep in while marking the position of thread.

## DISCUSSION

1. The Gravesand's apparatus can also be used to verify the parallelogram law of vector addition for forces as well as triangle law of vector addition. This can be done by using the same procedure by replacing the unknown weight by a standard weight.

2. The method described above to find the point of no-friction for the junction of three threads is quite good experimentally. If you like to check up by an alternative method, move the junction to extreme left, extreme right, upper most and lower most positions where it can stay and friction is maximum. The centre of these four positions is the point of no-friction.

3. What is the effect of not locating the point of no-friction accurately? In addition to the three forces due to weight, there is a fourth force due to friction. These four are in equilibrium. Thus, the resultant of $P$ and $Q$ may not be vertically upwards, i.e., exactly opposite to the direction of X.

4. It is advised that values of $P$ and $Q$ may be checked by spring balance as slotted weights may have large error in their marked value. Also check up the result for X by spring balance.

## SELF ASSESSMENT

1. State parallelogram law of vector addition.
2. Given two forces, what could be the
   (a) Maximum magnitude of resultant force.
   (b) Minimum magnitude of resultant force.
3. In which situation this parallelogram can be a rhombus.
4. If all the three forces are equal in magnitude, how will the parallelogram modify?
5. When the knot is in equilibrium position, is any force acting on the pulleys?

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Interchange position of the body of unknown weight with either of the forces and then find out the weight of that body.
2. Keeping the two forces same and by varying the unknown weight, study the angle between the two forces.
3. Suggest suitable method to estimate the density of material of a given cylinder using parallelogram law of vectors.
4. Implement parallelogram law of vectors in the following situations:-

   (a) Catapult (b) Bow and arrow (c) Hand gliding
   (d) Kite (e) Cycle pedalling

# EXPERIMENT 6

## AIM

Using a Simple Pendulum plot L – T and L – $T^2$ graphs, hence find the effective length of second's pendulum using appropriate graph.

## APPARATUS AND MATERIAL REQUIRED

Clamp stand; a split cork; a heavy metallic (brass/iron) spherical bob with a hook; a long, fine, strong cotton thread/string (about 2.0 m); stop-watch; metre scale, graph paper, pencil, eraser.

## DESCRIPTION OF TIME MEASURING DEVICES IN A SCHOOL LABORATORY

The most common device used for measuring time in a school laboratory is a stop-watch or a stop-clock (analog). As the names suggest, these have the provision to start or stop their working as desired by the experimenter.

**(a) Stop-Watch**

**Analog**

A stop-watch is a special kind of watch. It has a multipurpose knob or button (B) for start/stop/back to zero position [Fig. E 6.1(b)]. It has two circular dials, the bigger one for a longer second's hand and the other smaller one for a shorter minute's hand. The second's dial has 30 equal divisions, each division representing 0.1 second. Before using a stop-watch you should find its least count. In one rotation, the seconds hand covers 30 seconds (marked by black colour) then in the second rotation another 30 seconds are covered (marked by red colour), therefore, the least count is 0.1 second.

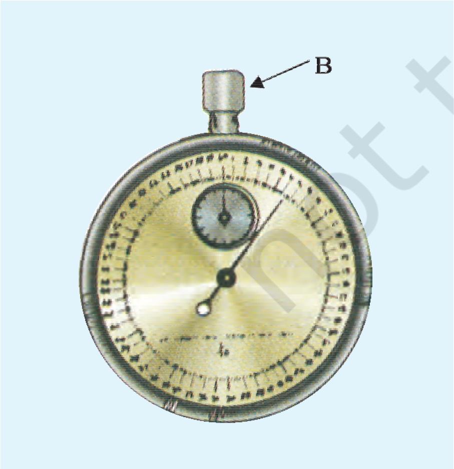



***Fig.E 6.1(a):*** *Stop - Watch*

**(b) Stop-Clock**

The least count of a stop-watch is generally about 0.1s [Fig. E 6.1(b)] while that of a stop-clock is 1s, so for more accurate measurement of time intervals in a school laboratory, a stop-watch is preferred. Digital stop-watches are also available now. These watches may be started by pressing the button and can be stopped by pressing the same button

once again. The lapsed time interval is directly displayed by the watch.

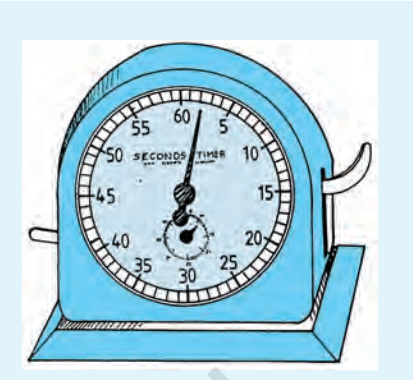



*Fig.E 6.1(b): Stop - Clock*

## TERMS AND DEFINITIONS

1. **Second's pendulum:** It is a pendulum which takes precisely one second to move from one extreme position to other. Thus, its times period is precisely 2 seconds.
2. **Simple pendulum:** A point mass suspended by an inextensible, mass less string from a rigid point support. In practice a small heavy spherical bob of high density material of radius *r*, much smaller than the length of the suspension, is suspended by a light, flexible and strong string/thread supported at the other end firmly with a clamp stand. Fig. E 6.2 is a good approximation to an ideal simple pendulum.
3. **Effective length of the pendulum:** The distance $L$ between the point of suspension and the centre of spherical bob (centre of gravity), $L = l + r + e$, is also called the effective length where $l$ is the length of the string from the top of the bob to the hook, $e$, the length of the hook and $r$ the radius of the bob.

## PRINCIPLE

The simple pendulum executes **Simple Harmonic Motion** (SHM) as the acceleration of the pendulum bob is directly proportional to its displacement from the mean position and is always directed towards it.

The time period (T) of a simple pendulum for oscillations of small amplitude, is given by the relation

$$T = 2\pi\sqrt{L/g} \qquad \text{(E 6.1)}$$

where $L$ is the length of the pendulum, and $g$ is the acceleration due to gravity at the place of experiment.

Eq. (6.1) may be rewritten as

$$T^2 = \frac{4\pi^2 L}{g} \qquad \text{(E 6.2)}$$

## PROCEDURE

1. Place the clamp stand on the table. Tie the hook, attached to the pendulum bob, to one end of the string of about 150 cm in length. Pass the other end of the string through two half-pieces of a split cork.

2. Clamp the split cork firmly in the clamp stand such that the line of separation of the two pieces of the split cork is at right angles to the line OA along which the pendulum oscillates [Fig. E 6.2(a)]. Mark, with a piece of chalk or ink, on the edge of the table a vertical line parallel to and just behind the vertical thread OA, the position of the bob at rest. Take care that the bob hangs vertically (about 2 cm above the floor) beyond the edge of the table so that it is free to oscillate.

3. Measure the effective length of simple pendulum as shown in Fig. E 6.2(b).

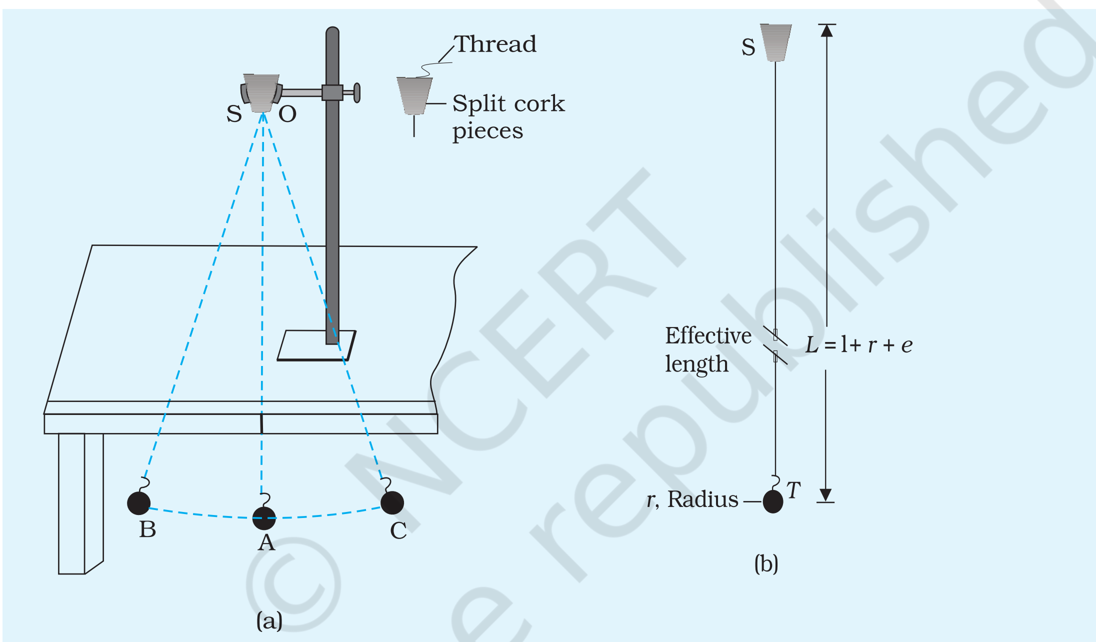



***Fig.E 6.2 (a):*** *A simple pendulum; B and C show the extreme positions*

***Fig.E 6.2 (b):*** *Effective length of a simple pendulum*

4. Displace the bob to one side, not more than 15 degrees angular displacement, from the vertical position OA and then release it gently. In case you find that the stand is shaky, put some heavy object on its base. Make sure that the bob starts oscillating in a vertical plane about its rest (or mean) position OA and **does not** (i) spin about its own axis, or (ii) move up and down while oscillating, or (iii) revolve in an elliptic path around its mean position.

5. Keep the pendulum oscillating for some time. After completion of a few oscillations, start the stop-watch/clock as the thread attached to the pendulum bob just crosses its mean position (say, from left to right). Count it as zero oscillation.

6. Keep on counting oscillations 1,2,3,..., $n$, everytime the bob crosses the mean position OA in the same direction (from left to right).

Stop the stop-watch/clock, at the count $n$ (say, 20 or 25) of oscillations, i.e., just when $n$ oscillations are complete. For better results, $n$ should be chosen such that the time taken for $n$ oscillations is 50 s or more. Read, the total time ($t$) taken by the bob for $n$ oscillations. Repeat this observation a few times by noting the time for same number ($n$) of oscillations. Take the mean of these readings. Compute the time for one oscillation, i.e., the time period $T$ ( = $t/n$) of the pendulum.

7. Change the length of the pendulum, by about 10 cm. Repeat the step 6 again for finding the time (t) for about 20 oscillations or more for the new length and find the mean time period. Take 5 or 6 more observations for different lengths of penduLum and find mean time period in each case.

8. Record observations in the tabular form with proper units and significant figures.

9. Take effective length $L$ along x-axis and $T^2$ (or $T$) along y-axis, using the observed values from Table E 6.1. Choose suitable scales on these axes to represent $L$ and $T^2$ (or $T$). Plot a graph between $L$ and $T^2$ (as shown in Fig. E 6.4) and also between $L$ and $T$ (as shown in Fig. E 6.3). What are the shapes of $L$–$T^2$ graph and $L$–$T$ graph? Identify these shapes.

## OBSERVATIONS

(i) Radius ($r$) of the pendulum bob (given) = ... cm

Length of the hook (given) (e) = ... cm

Least count of the metre scale = ... mm = ... cm

Least count of the stop-watch/clock = ... s

**Table E 6.1: Measuring the time period *T* and effective length *L* of the simple pendulum**

| S. No. | Length of the string from the top of the bob to the point of suspension $l$ | Effective length, $L = (l+r+e)$ | | Number of oscillations counted, $n$ | Time for $n$ oscillations $t$ (s) | | | | Time period $T$ (= $t/n$) |
|---|---|---|---|---|---|---|---|---|---|
| | cm | (cm) | m | | (i)... | (ii) | (iii) | Mean $t$ (s) | s |
| | | | | | | | | | |
| | | | | | | | | | |

## PLOTTING GRAPH

**(i) *L* vs *T* graphs**

Plot a graph between $L$ versus $T$ from observations recorded in Table E 6.1, taking $L$ along x-axis and $T$ along y-axis. You will find that this graph is a curve, which is part of a parabola as shown in Fig. E 6.3.

**(ii) *L* vs $T^2$ graph**

Plot a graph between $L$ versus $T^2$ from observations recorded in Table E 6.1, taking $L$ along x-axis and $T^2$ along y-axis. You will find that the graph is a straight line passing through origin as shown in Fig. E. 6.4.

**(iii)** From the $T^2$ versus $L$ graph locate the effective length of second's pendulum for $T^2 = 4s^2$.

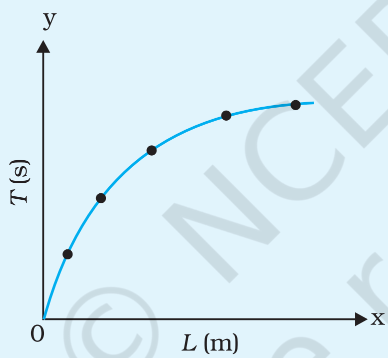



***Fig. E 6.3:*** *Graph of L vs T*

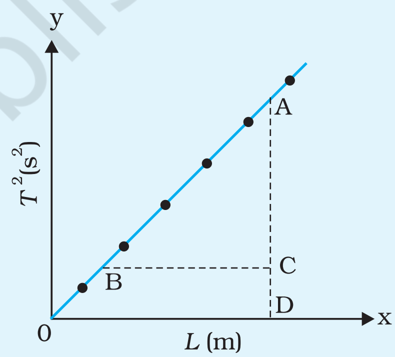



***Fig. E 6.4:*** *Graph L vs* $T^2$

## RESULT

1. The graph $L$ versus $T$ is curved, convex upwards.
2. The graph $L$ versus $T^2$ is a straight line.
3. The effective length of second's pendulum from $L$ versus $T^2$ graph is ... cm.

**Note :** The radius of bob may be found from its measured diameter with the help of callipers by placing the pendulum bob between the two jaws of (a) ordinary callipers, or (b) Vernier Callipers, as described in Experiment E 1.1 (a). It can also be found by placing the spherical bob between two parallel card boards and measuring the spacing (diameter) or distance between them with a metre scale.

## DISCUSSION

1. The accuracy of the result for the length of second's pendulum depends mainly on the accuracy in measurement of effective length (using metre scale) and the time period $T$ of the pendulum (using stop-watch). As the time period appears as $T^2$ in Eq. E 6.2, a small uncertainty in the measurement of $T$ would result in appreciable error in $T^2$, thereby significantly affecting the result. A stop-watch with accuracy of 0.1s may be preferred over a less accurate stop-watch/clock.

2. Some personal error is always likely to be involved due to stop-watch not being started or stopped exactly at the instant the bob crosses the mean position. Take special care that you start and stop the stop-watch at the instant when pendulum bob just crosses the mean position in the same direction.

3. Sometimes air currents may not be completely eliminated. This may result in conical motion of the bob, instead of its motion in vertical plane. The spin or conical motion of the bob may cause a twist in the thread, thereby affecting the time period. Take special care that the bob, when it is taken to one side of the rest position, is released very gently.

4. To suspend the bob from the rigid support, use a thin, light, strong, unspun cotton thread instead of nylon string. Elasticity of the string is likely to cause some error in the effective length of the pendulum.

5. The simple pendulum swings to and fro in SHM about the mean, equilibrium position. Eq. (E 6.1) that expresses the relation between $T$ and $L$ as $T = 2\pi\sqrt{L/g}$, holds strictly true for small amplitude or swing $\theta$ of the pendulum.

   Remember that this relation is based on the assumption that sin $\theta \approx \theta$, (expressed in radian) holds only for small angular displacement $\theta$.

6. Buoyancy of air and viscous drag due to air slightly increase the time period of the pendulum. The effect can be greatly reduced to a large extent by taking a small, heavy bob of high density material (such as iron/ steel/brass).

## SELF ASSESSMENT

1. Interpret the graphs between $L$ and $T^2$, and also between $L$ and $T$ that you have drawn for a simple pendulum.

2. Examine, using Table E 6.1, how the time period $T$ changes as the

effective length $L$ of a simple pendulum; becomes 2-fold, 4-fold, and so on.

3. How can you determine the value of '$g$', acceleration due to gravity, from the $T^2$ vs $L$ graph?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. To determine '$g$', the acceleration due to gravity, at a given place, from the $L - T^2$ graph, for a simple pendulum.

2. Studying the effect of size of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few spherical bobs of same material (density) but of different sizes (diameters). Keep the length of the pendulum the same for each case. Clamp the bobs one by one, and starting from a small angular displacement of about 10°, each time measure the time for 50 oscillations. Find out the time period of the pendulum using bobs of different sizes. Compensate for difference in diameter of the bob by adjusting the length of the thread.

   Does the time period depend on the size of the pendulum bob? If yes, see the order in which the change occurs.]

3. Studying the effect of material (density) of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few spherical bobs (balls) of different materials, but of same size. Keep the length of the pendulum the same for each case. Find out, in each case starting from a small angular displacement of about 10°, the time period of the pendulum using bobs of different materials,

   Does the time period depend on the material (density) of the pendulum bob? If yes, see the order in which the change occurs. If not, then do you see an additional reason to use the pendulum for time measurement.]

4. Studying the effect of mass of the bob on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, take a few bobs of different materials (different masses) but of same size. Keep the length of the pendulum same for each case. Starting from a small angular displacement of about 10° find out, in each case, the time period of the pendulum, using bobs of different masses.

   Does the time period depend on the mass of the pendulum bob? If yes, then see the order in which the change occurs. If not, then do you see an additional reason to use the pendulum as a time measuring device.]

5. Studying the effect of amplitude of oscillation on the time period of the simple pendulum.

   [**Hint:** With the same experimental set-up, keep the mass of the bob and length of the pendulum fixed. For measuring the angular amplitude, make a large protractor on the cardboard and have a scale marked on an arc from 0° to 90° in units of 5°. Fix it on the edge of a table by two drawing pins such that its 0°- line coincides

with the suspension thread of the pendulum at rest. Start the pendulum oscillating with a very large angular amplitude (say 70°) and find the time period $T$ of the pendulum. Change the amplitude of oscillation of the bob in small steps of 5° or 10° and determine the time period in each case till the amplitude becomes small (say 5°). Draw a graph between angular amplitude and $T$. How does the time period of the pendulum change with the amplitude of oscillation?

How much does the value of $T$ for $A$ = 10° differ from that for $A$= 50° from the graph you have drawn?

Find at what amplitude of oscillation , the time period begins to vary?

Determine the limit for the pendulum when it ceases to be a simple pendulum.]

6. Studying the effect on time period of a pendulum having a bob of varying mass (e.g. by filling the hollow bob with sand, sand being drained out in steps)

[**Hint:** The change in $T$, if any, in this experiment will be so small that it will not be possible to measure it due to the following reasons:

The centre of gravity (CG) of a hollow sphere is at the centre of the sphere. The length of this simple pendulum will be same as that of a solid sphere (same size) or that of the hollow sphere filled completely with sand (solid sphere).

Drain out some sand from the sphere. The situation is as shown in Fig. E. 6.5. The CG of bob now goes down to point say A. The effective length of the pendulum increases and therefore the $T_A$ increases ($T_A > T_O$), some more sand is drained out, the CG goes down further to a point B. The effective length further increases, increasing $T$.

The process continues and $L$ and $T$ change in the same direction (increasing), until finally the entire sand is drained out. The bob is now a hollow sphere with CG shifting back to centre C. The time period will now become $T_0$ again.]

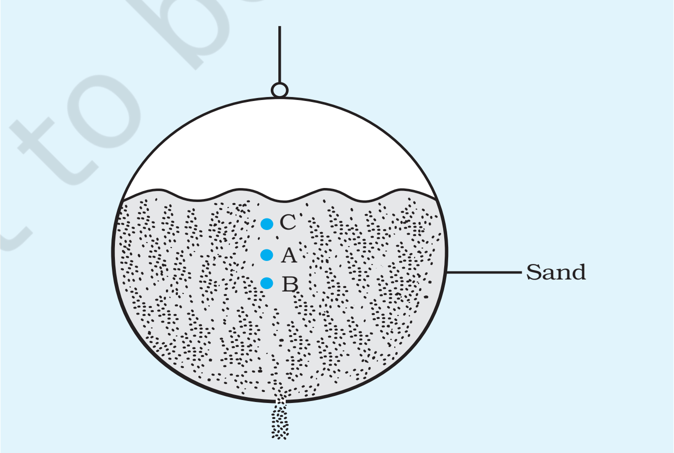



***Fig. E 6.5:*** *Variation of centre of gravity of sand filled hollow bob on time period of the pendulum; sand being drained out of the bob in steps.*

# EXPERIMENT 7

## AIM

To study the relation between force of limiting friction and normal reaction and to find the coefficient of friction between surface of a moving block and that of a horizontal surface.

## APPARATUS AND MATERIAL REQUIRED

A wooden block with a hook, a horizontal plane with a glass or laminated table top (the table top itself may be used as a horizontal plane), a frictionless pulley which can be fixed at the edge of the horizontal table/plane, spirit level, a scale, pan, thread or string, spring balance, weight box and five masses of 100 g each.

## TERMS AND DEFINITIONS

**Friction:** The tendency to oppose the relative motion between two surfaces in contact is called friction.

**Static Friction:** It is the frictional force acting between two solid surfaces in contact at rest but having a tendency to move (slide) with respect to each other.

**Limiting Friction:** It is the maximum value of force of static friction when one body is at the verge of sliding with respect to the other body in contact.

**Kinetic (or Dynamic) Friction:** It is the frictional force acting between two solid surfaces in contact when they are in relative motion.

## PRINCIPLE

The maximum force of static friction, *i.e.*, limiting friction, $F_L$, between two dry, clean and unlubricated solid surfaces is found to obey the following empirical laws:

(i) The limiting friction is

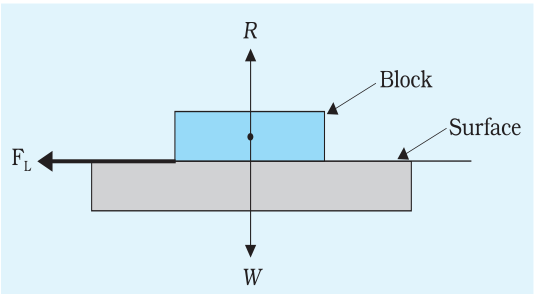



***Fig. E 7.1:*** *The body is at rest due to static friction*

directly proportional to the normal reaction, $R$, which is given by the total weight $W$ of the body (Fig. E 7.1). The line of action is same for both $W$ and $R$ for horizontal surface,

$$F_L \propto R \Rightarrow F_L = \mu_L R$$

$$\text{i.e.} \quad \mu_L = \frac{F_L}{R}$$

Thus, the ratio of the magnitude of the limiting friction, $F_L$, to the magnitude of the normal force, $R$, is a constant known as the coefficient of limiting friction ($\mu_L$) for the given pair of surfaces in contact.

(ii) The limiting friction depends upon the nature of surfaces in contact and is nearly independent of the surface area of contact over wide limits so long as normal reaction remains constant.

Note that $F_L = \mu_L R$ is an equation of a straight line passing through the origin. Thus, the slope of the straight-line graph between $F_l$ (along Y-axis) and $R$ (along X-axis) will give the value of coefficient of limiting friction $\mu_L$.

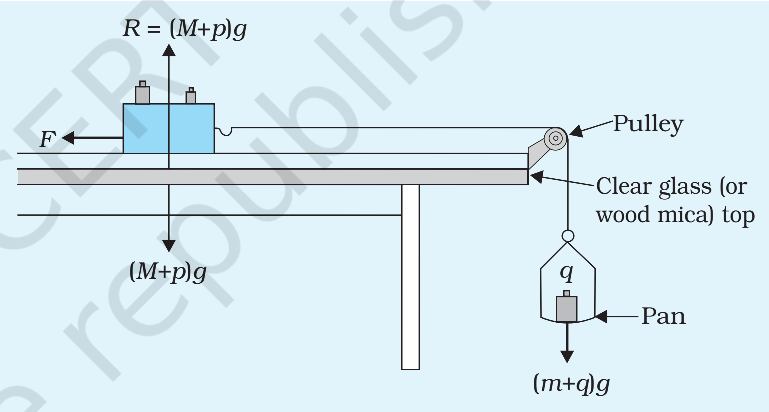



**Fig. E 7.2:** *Experimental set up to study limiting friction*

In this experiment, the relationship between the limiting friction and normal reaction is studied for a wooden block. The wooden block is made to slide over a horizontal surface (say glass or a laminated surface) (Fig. E 7.2).

## PROCEDURE

1. Find the range and least count of the spring balance.
2. Measure the mass ($M$) of the given wooden block with hooks on its sides and the scale pan ($m$) with the help of the spring balance.
3. Place the glass (or a laminated sheet) on a table and make it horizontal, if required, by inserting a few sheets of paper or cardboard below it. To ensure that the table-top surface is horizontal use a spirit level. Take care that the top surface must be clean and dry.

4. Fix a frictionless pulley on one edge of table-top as shown in Fig. E 7.2. Lubricate the pulley if need be.

5. Tie one end of a string of suitable length (in accordance with the size and the height of the table) to a scale pan and tie its other end to the hook of the wooden block.

6. Place the wooden block on the horizontal plane and pass the string over the pulley (Fig. E7.2). Ensure that the portion of the string between pulley and the wooden block is horizontal. This can be done by adjusting the height of the pulley to the level of hook of block.

7. Put some mass ($q$) on the scale pan. Tap the table-top gently with your finger. Check whether the wooden block starts moving.

8. Keep on increasing the mass ($q$) on the scale pan till the wooden block just starts moving on gently tapping the glass top. Record the total mass kept on the scale pan in Table E 7.1.

9. Place some known mass (say $p$ ) on the top of wooden block and adjust the mass ($q'$) on the scale pan so that the wooden block alongwith mass $p$ just begins to slide on gently tapping the table top. Record the values of $p'$ and $q'$ in Table E 7.1.

10. Repeat step 9 for three or four more values of $p$ and record the corresponding values of $q$ in Table E 7.1. A minimum of five observations may be required for plotting a graph between $F_L$ and $R$.

## OBSERVATIONS

1. Range of spring balance = ... to ... g
2. Least count of spring balance = ... g
3. Mass of the scale pan, ($m$) = ... g
4. Mass of the wooden block ($M$) = ... g
5. Acceleration due to gravity ($g$) at the place of experiment= ... m/s$^2$

**Table E 7.1: Variation of Limiting Friction with Normal Reaction**

| S. No. | Mass on the wooden block ($p$) (g) | | Normal force $R$ due to mass ($M$+$p$) | | Mass on the pan ($q$) g | Force of limiting friction $F_L$ | Coefficient of friction $\mu_L = \frac{F_L}{R}$ | Mean $\mu_L$ |
|---|---|---|---|---|---|---|---|---|
| | (g) | (kg) | N | (g) | (kg) | (N) | | |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |

## GRAPH

Plot a graph between the limiting friction ($F_L$) and normal force ($R$) between the wooden block and the horizontal surface, taking the limiting friction $F_L$ along the y-axis and normal force $R$ along the x-axis. Draw a line to join all the points marked on it (Fig. E 7.3). Some points may not lie on the straight-line graph and may be on either side of it. Extend the straight line backwards to check whether the graph passes through the origin. The slope of this straight-line graph gives the coefficient of limiting friction ($\mu_L$) between the wooden block and the horizontal surface. To find the slope of straight line, choose two points A and B that are far apart from each other on the straight line as shown in Fig. E 7.3. Draw a line parallel to x-axis through point A and another line parallel to y-axis through point B. Let point Z be the point of intersection of these two lines. Then, the slope $\mu_L$ of straight line graph AB would be

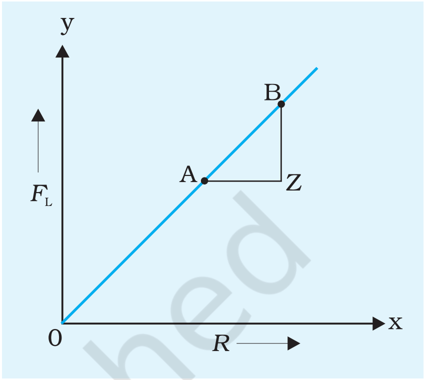



***Fig. E 7.3:** Graph between force of limiting friction $F_L$ and normal reaction, R*

$$\mu_L = \frac{F_L}{R} = \frac{BZ}{AZ}$$

## RESULT

The value of coefficient of limiting friction $\mu_L$ between surface of wooden block and the table-top (laminated sheet/glass) is:

(i) From calculation (Table E 7.1) = ...

(ii) From graph = ...

## PRECAUTIONS

1. Surface of the table should be horizontal and dust free.
2. Thread connecting wooden block and pulley should be horizontal.
3. Friction of the pulley should be reduced by proper oiling.
4. Table top should always be tapped gently.

## SOURCES OF ERROR

1. Always put the mass at the centre of wooden block.
2. Surface must be dust free and dry.
3. The thread must be unstretchable and unspun.

## DISCUSSION

1. The friction depends on the roughness of the surfaces in contact. If the surfaces in contact are ideally (perfactly) smooth, there would be no friction between the two surfaces. However, there cannot be an ideally smooth surface as the distribution of atoms or molecules on solid surface results in an inherent roughness.

2. In this experimental set up and calculations, friction at the pulley has been neglected, therefore, as far as possible, the pulley, should have minimum friction as it cannot be frictionless.

3. The presence of dust particles between the wooden block and horizontal plane surface may affect friction and therefore lead to errors in observations. Therefore, the surface of the horizontal plane and wooden block in contact must be clean and dust free.

4. The presence of water or moisture between the wooden block and the plane horizontal surface would change the nature of the surface. Thus, while studying the friction between the surface of the moving body and horizontal plane these must be kept dry.

5. Elasticity of the string may cause some error in the observation. Therefore, a thin, light, strong and unspun cotton thread must be used as a string to join the scale pan and the moving block.

6. The portion of string between the pulley and wooden block must be horizontal otherwise only a component of tension in the string would act as the force to move the block.

7. It is important to make a judicious choice of the size of the block and set of masses for this experiment. If the block is too light, its force of limiting friction may be even less than the weight of empty pan and in this situation, the observation cannot be taken with the block alone. Similarly, the maximum mass on the block, which can be obtained by putting separate masses on it, should not be very large otherwise it would require a large force to make the block move.

8. The additional mass, *p*, should always be put at the centre of wooden block.

9. The permissible error in measurements of coefficient of friction

$$= \frac{\Delta F_L}{F_L} + \frac{\Delta R}{R} = \ldots$$

## SELF ASSESSMENT

1. On the basis of your observations, find the relation between limiting friction and the mass of sliding body.
2. Why do we not choose a spherical body to study the limiting friction between the two surfaces?
3. Why should the horizontal surfaces be clean and dry?
4. Why should the portion of thread between the moving body and pulley be horizontal?
5. Why is it essential in this experiment to ensure that the surface on which the block moves should be horizontal?
6. Comment on the statement: "The friction between two surfaces can never be zero".
7. In this experiment, usually unpolished surfaces are preferred, why?
8. What do you understand by self-adjusting nature of force of friction?
9. In an experiment to study the relation between force of limiting friction and normal reaction, a body just starts sliding on applying a force of 3 N. What will be the magnitude of force of friction acting on the body when the applied forces on it are 0.5 N, 1.0 N, 2.5 N, 3.5 N, respectively.



**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. To study the effect of the nature of sliding surface. [**Hint:** Repeat the same experiment for different types of surfaces say, plywood, carpet etc. Or repeat the experiment after putting oil or powder on the surface.]
2. To study the effect of changing the area of the surfaces in contact. [**Hint:** Place the wooden block vertically and repeat the experiment. Discuss whether the readings and result of the experiment are same.]
3. To find the coefficient of limiting friction by sliding the block on an inclined plane.

# EXPERIMENT 8

## AIM

To find the downward force, along an inclined plane, acting on a roller due to gravity and study its relationship with the angle of inclination by plotting graph between force and sin $\theta$.

## APPARATUS AND MATERIAL REQUIRED

Inclined plane with protractor and pulley, roller, weight box, spring balance, spirit level, pan and thread.

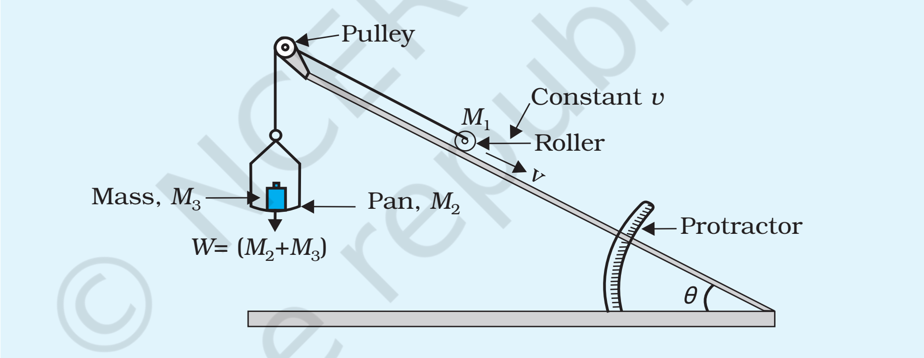



***Fig. E 8.1:*** *Experimental set up to find the downward force along an inclined plane*

## PRINCIPLE

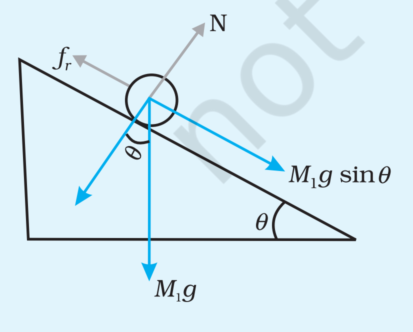



***Fig. E 8.2:*** *Free body diagram*

Consider the set up shown in Fig. E 8.1. Here a roller of mass $M_1$ has been placed on an inclined plane making an angle $\theta$ with the horizontal. An upward force, along the inclined plane, could be applied on the mass $M_1$ by adjusting the weights on the pan suspended with a string while its other end is attached to the mass through a pulley fixed at the top of the inclined plane. The force on the the mass $M_1$ when it is moving with a constant velocity $v$ will be

$$W = M_1 g \sin\theta - f_r$$

where $f_r$ is the force of friction due to rolling, $M_1$ is mass of roller and $W$ is the total tension in the string

($W$ = weight suspended). Assuming there is no friction between the pulley and the string.

## PROCEDURE

1. Arrange the inclined plane, roller and the masses in the pan as shown in Fig. E. 8.1. Ensure that the pulley is frictionless. Lubricate it using machine oil, if necessary.
2. To start with, let the value of $W$ be adjusted so as to permit the roller to stay at the top of the inclined plane at rest.
3. Start decreasing the masses in small steps in the pan until the roller just starts moving down the plane with a constant velocity. Note $W$ and also the angle $\theta$. Fig. E 8.2 shows the free body diagram for the situation when the roller just begins to move downwards.
4. Repeat steps 2 and 3 for different values of $\theta$. Tabulate your observations.

## OBSERVATIONS

Acceleration due to gravity, $g$ = ... $ms^{-2}$

Mass of roller, $m$ = ($M_1$) g

Mass of the pan = ($M_2$) g

**Table E 8.1**

| S. No. | $\theta°$ | $\sin\theta$ | Mass added to pan $M_3$ | Force $W = (M_2 + M_3)\, g$ (N) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

## PLOTTING GRAPH

Plot graph between $\sin\theta$ and the force $W$ (Fig. E 8.3). It should be a straight line.

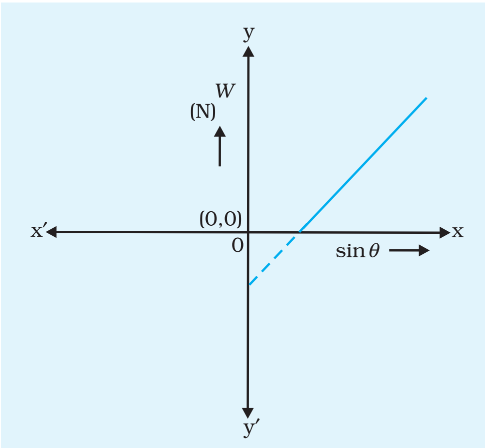



***Fig. E 8.3:*** *Graph between W and sin θ*

## RESULT

Therefore, within experimental error, downward force along inclined plane is directly proportional to sin $\theta$, where $\theta$ is the angle of inclination of the plane.

## PRECAUTIONS

1. Ensure that the inclined plane is placed on a horizontal surface using the spirit level.
2. Pulley must be frictionless.
3. The weight should suspend freely without touching the table or other objects.
4. Roller should roll smoothly, that is, without slipping.
5. Weight, $W$ should be decreased in small steps.

## SOURCES OF ERROR

1. Error may creep in due to poor judgement of constant velocity.
2. Pulley may not be frictionless.
3. It may be difficult to determine the exact point when the roller begins to slide with constant velocity.
4. The inclined surface may not be of uniform smoothness/roughness.
5. Weights in the weight box may not be standardised.

## DISCUSSION

As the inclination of the plane is increased, starting from zero, the value of $mg \sin\theta$ increases and frictional force also increases accordingly. Therefore, till limiting friction $W = 0$, we need not apply any tension in the string.

When we increase the angle still further, net tension in the string is required to balance $(mg \sin\theta - f_r)$ or otherwise the roller will accelerate downwards.

It is difficult to determine exact value of $W$. What we can do is we find tension $W_1$ (< $W$) at which the roller is just at the verge of rolling down and $W_2$ (> $W$) at which the roller is just at the verge of moving up. Then we can take

$$W = \frac{(W_1 + W_2)}{2}$$

## SELF ASSESSMENT

1. Give an example where the force of friction is in the same direction as the direction of motion.
2. How will you use the graph to find the co-efficient of rolling friction between the roller and the inclined plane?
3. What is the relation between downward force and angle of inclination of the plane?
4. How will you ensure that the roller moves upward/downward with constant velocity?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. From the graph, find the intercept and the slope. Interpret them using the given equation.
2. Allow the roller to move up the inclined plane by adjusting the mass in the pan. Interpret the graph between $W'$ and sin $\theta$ where $W'$ is the mass in pan added to the mass of the pan required to allow the roller to move upward with constant velocity.

# EXPERIMENT 9

## AIM

To determine Young's modulus of the material of a given wire by using Searle's apparatus.

## APPARATUS AND MATERIAL REQUIRED

Searle's apparatus, slotted weights, experimental wire, screw gauge and spirit level.

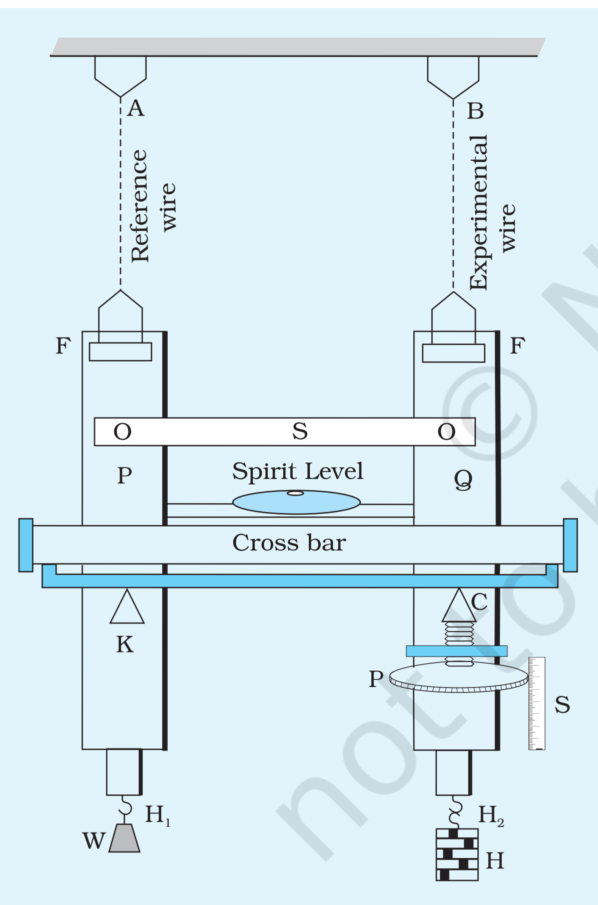



***Fig. E 9.1:*** *Searle's apparatus for determination of Y*

**SEARLE'S APPARATUS**

It consists of two metal frames P and Q hinged together such that they can move relative to each other in vertical direction (Fig. E9.1).

A spirit level is supported on a rigid crossbar frame which rests on the tip of a micrometer screw C at one end and a fixed knife edge K at the other. Screw C can be moved vertically. The micrometer screw has a disc having 100 equal divisions along its circumference. On the side of it is a linear scale S, attached vertically. If there is any relative displacement between the two frames, P and Q, the spirit level no longer remains horizontal and the bubble of the spirit level is displaced from its centre. The crossbar can again be set horizontal with the help of micrometer screw and the spirit level. The distance through which the screw has to be moved gives the relative displacement between the two frames.

The frames are suspended by two identical long wires of the same material, from the same rigid horizontal support. Wire B is called the experimental wire and wire A acts as a reference wire. The frames, P and Q, are provided with hooks $H_1$ and $H_2$ at their lower ends from which weights are suspended. The hook $H_1$ attached to the reference wire carries a constant weight *W* to keep the wire taut.

To the hook $H_2$ is attached a hanger on which slotted weights can be placed to apply force on the experimental wire.

## PRINCIPLE

The apparatus works on the principle of Hookes' Law. If $l$ is the extension in a wire of length $L$ and radius $r$ due to force $F$ (=$Mg$), the Young's modulus of the material of the given wire, $Y$, is

$$Y = \frac{MgL}{\pi r^2 l}$$

## PROCEDURE

1. Suspend weights from both the hooks so that the two wires are stretched and become free from any kinks. Attach only the constant weight $W$ on the reference wire to keep it taut.
2. Measure the length of the experimental wire from the point of its support to the point where it is attached to the frame.
3. Find the least count of the screw gauge. Determine the diameter of the experimental wire at about 5 places and at each place in two mutually perpendicular directions. Find the mean diameter and hence the radius of the wire.
4. Find the pitch and the least count of the miocrometer screw attached to the frame. Adjust it such that the bubble in the spirit level is exactly in the centre. Take the reading of the micrometer.
5. Place a load on the hanger attached to the experimental wire and increase it in steps of 0.5 kg. For each load, bring the bubble of the spirit level to the centre by adjusting the micrometer screw and then note its reading. Take precautions to avoid backlash error.
6. Take about 8 observations for increasing load.
7. Decrease the load in steps of 0.5 kg and each time take reading on micrometer screw as in step 5.

## OBSERVATIONS

Length of the wire ($L$) = ...

Pitch of the screw gauge = ...

No. of divisions on the circular scale of the screw gauge = ...

Least count (L.C.) of screw gauge = ...

Zero error of screw gauge = ...

**Table E 9.1: Measurement of diameter of wire**

| S. No. | Reading along any direction | | | Reading along perpendicular direction | | | Mean diameter $d = \frac{d_1 + d_2}{2}$ (cm) |
|---|---|---|---|---|---|---|---|
| | Main scale reading $S$ (cm) | Circular scale reading $n$ | Diameter $d_1 = S + n \times$ L.C. | Main scale reading $S$ (cm) | Circular scale reading $n$ | Diameter $d_2 = S + n \times$ L.C. (cm) | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |

Mean diameter (corrected for zero error) = ...

Mean radius = ...

**MEASUREMENT OF EXTENSION $l$**

Pitch of the micrometer screw = ...

No. of divisions on the circular scale = ...

Least count (L.C.) of the micrometer screw = ...

Acceleration due to gravity, $g$ = ...

**Table E 9.2: Measurement of extension with load**

| S. No. | Load on experimental wire $M$ | Micrometer reading | | Mean reading $\frac{x + y}{2}$ (cm) |
|---|---|---|---|---|
| | (kg) | Load increasing $x$ (cm) | Load decreasing $y$ (cm) | |
| 1 | 0.5 | | | a |
| 2 | 1.0 | | | b |
| 3 | 1.5 | | | c |
| 4 | 2.0 | | | d |
| 5 | 2.5 | | | e |
| 6 | 3.0 | | | f |
| 7 | 3.5 | | | g |
| 8 | 4.0 | | | h |

## CALCULATION

Observations recorded in Table E 9.2 can be utilised to find extension of experimental wire for a given load, as shown in Table E 9.3.

**Table E 9.3: Calculating extension for a given load**

| S. No. | Load (kg) | Mean extension (cm) | Load (kg) | Mean extension (cm) | Extension $l$ for 1.5 kg |
|---|---|---|---|---|---|
| 1. | 0.5 | (a) | 2.0 | (d) | d – a |
| 2. | 1.0 | (b) | 2.5 | (e) | e – b |
| 3. | 1.5 | (c) | 3.0 | (f) | f – c |

$$\therefore \text{Mean } l = \frac{(a-d)+(b-c)+(c-f)}{3}$$

$$= \ldots \text{ cm for 1.5 kg}$$

Young's modulus, Y, of experimental wire $Y = \dfrac{MgL}{\pi r^2 l} = \ldots \text{N/m}^2$

## GRAPH

The value of $Y$ can also be found by plotting a graph between $l$ and $Mg$. Draw a graph with load on the x-axis and extension on the y-axis. It should be a straight line. Find the slope $= \dfrac{\Delta l}{\Delta M}$ of the line. Using this value, find the value of $Y$.

## RESULT

The Young's modulus $Y$ of the material of the wire

(using half table method) $= Y \pm \Delta Y$ N/m²

(using graph) $= Y \pm \Delta Y$ N/m²

## ERROR

Uncertainty, $\Delta M$, in the measurement of $M$ can be determined by a beam/physical balance using standard weight box/or by using water bottles of fixed capacity.

Find the variation in $M$ for each slotted weight of equal mass say $\Delta M_1$ and $\Delta M_2$. Find the mean of these $\Delta M$. This is the uncertainity ($\Delta M$) in $M$.

$\Delta L$ – the least count of the scale used for measuring $L$.

$\Delta r$ – the least count of the micrometer screw gauge used for measuring $r$.

$\Delta l$ – least count of the device used for measuring extension.

## PRECAUTION

1. Measure the diameter of the wire at different positions, check for its uniformity.
2. Adjust the spirit level only after sufficient time gap following each loading/unloading.

## SOURCES OF ERROR

1. The diameter of the wire may alter while loading.
2. Backlash error of the device used for measuring extension.
3. The nonuniformity in thickness of the wire.

## DISCUSSION

Which of the quantities measured in the experiment is likely to have maximum affect on the accuracy in measurement of $Y$ (Young's modulus).

## SELF ASSESSMENT

1. If the length of the wire used is reduced what will be its effect on (a) extension on the wire and (b) stress on the wire.
2. Use wire of different radii ($r_1$, $r_2$, $r_3$) but of same material in the above experimental set up. Is there any change in the value of Young's modulus of elasticity of the material? Discuss your result.

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Repeat the experiment with wires of different materials, if available.
2. Change the length of the experimental wire, of same material and study its effect on the Young's modulus of elasticity of the material.

# EXPERIMENT 10

## AIM

To find the force constant and effective mass of a helical spring by plotting $T^2$ - $m$ graph using method of oscillation.

## APPARATUS AND MATERIAL REQUIRED

Light weight helical spring with a pointer attached at the lower end and a hook/ring for suspending it from a hanger, (diameter of the spring may be about 1-1.5 cm inside or same as that in a spring balance of 100 g); a rigid support, hanger and five slotted weights of 10 g each (in case the spring constant is of high value one may use slotted weight of 20 g), clamp stand, a balance, a measuring scale (15-30 cm) and a stop-watch (with least count of 0.1s).

## PRINCIPLE

Spring constant (or force constant) of a spring is given by

$$\text{Spring constant, } K = \frac{\textit{Restoring Force}}{\textit{Extension}} \qquad \text{(E 10.1)}$$

Thus, spring constant is the restoring force per unit extension in the spring. Its value is determined by the elastic properties of the spring. A given object is attached to the free end of a spring which is suspended from a rigid point support (a nail, fixed to a wall). If the object is pulled down and then released, it executes simple harmonic oscillations.

The time period ($T$) of oscillations of a helical spring of spring constant $K$ is given by the relation $T$,

$T = 2\pi\sqrt{\dfrac{m}{K}}$ where $m$ is the load that is the mass of the object. If the spring has a large mass of its own, the expression changes to

$$T = 2\pi\sqrt{\frac{m_o + m}{K}} \qquad \text{(E 10.2)}$$

where $m_o$ and $m$ define the effective mass of the spring system (the spring along with the pointer and the hanger) and the suspended object (load) respectively. The time period of a stiff spring (having large spring constant) is small.

One can easily eliminate the term $m_o$ of the spring system appearing in Eq. (E 10.2) by suspending two different objects (loads) of masses $m_1$ and $m_2$ and measuring their respective periods of oscillations $T_1$ and $T_2$. Then,

(E 10.3)
$$T_1 = 2\pi\sqrt{\frac{m_0 + m_1}{K}}$$

(E 10.4)
and
$$T_2 = 2\pi\sqrt{\frac{m_0 + m_2}{K}}$$

Eliminating $m_o$ from Eqs. (E 2.3) and (E 2.4), we get

(E 10.5)
$$K = \frac{4\pi^2 (m_1 - m_2)}{(T_1^2 - T_2^2)}$$

Using Eq. (E 10.5), and knowing the values of $m_1$, $m_2$, $T_1$ and $T_2$, the spring constant $K$ of the spring system can be determined.

## PROCEDURE

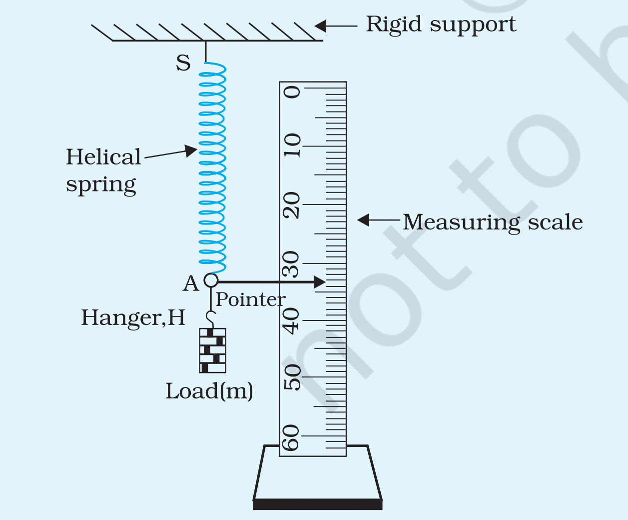



***Fig. E 10.1:*** *Experimental arrangement for studying spring constant of a helical spring*

1. Suspend the helical spring SA (having pointer P and the hanger H at its free end A), from a rigid support, as shown in Fig. E 10.1.
2. Set the measuring scale, close to the spring vertically. Take care that the pointer P moves freely over the scale without touching it.
3. Find out the least count of the measuring scale (It is usually 1mm or 0.1 cm).
4. Familiarise yourself with the working of the stop-watch and find its least count.
5. Suspend the load or slotted weight with mass $m_1$ on the hanger gently. Wait till the pointer comes to rest. This is the equilibrium position for the given load. Pull the load slightly downwards and then release it gently so that it is set into oscillations in a vertical plane

about its rest (or equilibrium) position. The rest position (x) of the pointer P on the scale is the reference or mean position for the given load. Start the stop-watch as the pointer P just crosses its mean position (say, from upwards to downwards) and simultaneously begin to count the oscillations.

6. Keep on counting the oscillations as the pointer crosses the mean position (x) in the same direction. Stop the watch after $n$ (say, 5 to 10) oscillations are complete. Note the time ($t$) taken by the oscillating load for $n$ oscillations.

7. Repeat this observation alteast thrice and in each occasion note the time taken for the same number ($n$) of oscillations. Find the mean time ($t_1$), for $n$ oscillations and compute the time for one oscillation, i.e., the time period $T_1$ (= $t_1/n$) of oscillating helical spring with a load $m_1$.

8. Repeat steps 5 and 6 for two more slotted weights.

9. Calculate time period of oscillation $T = \frac{t}{n}$ for each weight and tabulate your observations.

10. Compute the value of spring constant ($K_1$, $K_2$, $K_3$) for each load and find out the mean value of spring constant $K$ of the given helical spring.

11. The value of $K$ can also be determined by plotting a graph of $T^2$ vs $m$ with $T^2$ on y-axis and $m$ on x-axis.

   [**Note:** The number of oscillations, $n$, should be large enough to keep the error minimum in measurement of time. One convenient method to decide on the number $n$ is based on the least count of the stop-watch. If the least count of the stop-watch is 0.1 s. Then to have 1% error in measurement, the minimum time measured should be 10.0 s. Hence, the number $n$ for oscillations should be so chosen that oscillating mass takes more than 10.0 s to complete them.]

## OBSERVATIONS

Least count of the measuring scale = ... mm = ... cm

Least count of the stop-watch = ... s

Mass of load 1, $m_1$ = ... g = ... kg

Mass of load 2, $m_2$ = ... g = ... kg

Mass of load 3, $m_3$ = ... g = ... kg

**Table E 10.1: Measuring the time period $T$ of oscillations of helical spring with load**

| S. No. | Mass of the load, $m$ (kg) | Mean position of pointer, x (cm) | No. of oscillations, ($n$) | Time for ($n$) oscillations, $t$ (s) | | | | Time period, $T = t/n$ (s) |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | Mean $t$ (s) | |
| | | | | | | | | |

## CALCULATION

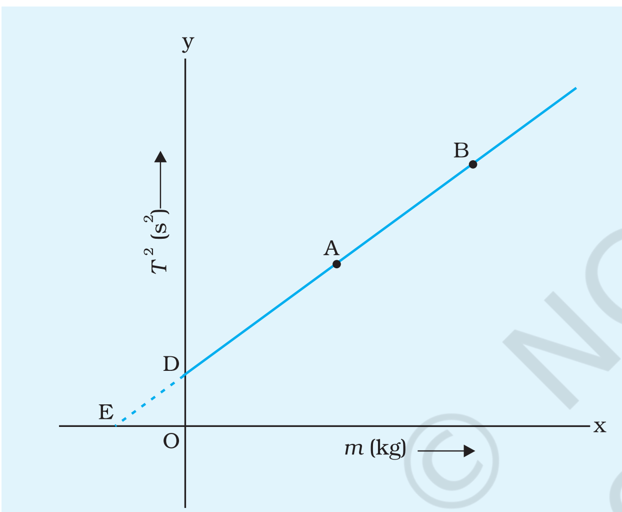



***Fig. E 10.2:*** *Expected graph between $T^2$ and m for a helical spring*

Substitute the values of $m_1$, $m_2$, $m_3$ and $T_1$, $T_2$, $T_3$, in Eq. (E 10.5):

$K_1 = 4\pi^2 (m_1 - m_2)/(T_1^{\,2} - T_2^{\,2})$;

$K_2 = 4\pi^2 (m_2 - m_3)/(T_2^{\,2} - T_3^{\,2})$;

$K_3 = 4\pi^2 (m_1 - m_3) / (T_1^{\,2} - T_3^{\,2})$

Compute the values of $K_1$, $K_2$ and $K_3$ and find the mean value of spring constant $K$ of the given helical spring. Express the result in proper SI units and significant figures.

Alternately one can also find the spring constant and effective mass of the spring from the graph between $T^2$ and $m$, which is expected to be a straight line as shown in Fig. E 10.2.

The value of spring constant $K$ ( $= 4\pi^2/m'$ ) of the helical spring can be calculated from the slope $m'$ of the straight line graph.

From the knowledge of intercept $c$ on y-axis and the slope $m$, the value of effective mass $m_o$ (= $c/m'$ ) of the helical spring can be computed. Alternatively, the effective mass $m_o$ (= $-c'$ ) of the helical spring can be directly computed from the knowledge of the intercept $c'$ made by the straight line on x-axis.

## RESULT

Spring constant of the given helical spring = ... N/m$^{-1}$

Effective mass of helical spring = ... g = ... kg

Error in $K$, can be calculated from the error in slope

$$\frac{\Delta K}{K} = \frac{\Delta slope}{slope}$$

The error in effective mass $m_0$ will be equal to the error in intercept and the error in slope. Once the error is calculated the result may be stated indicating the error.

## DISCUSSION

1. The accuracy in determination of the spring constant depends mainly on the accuracy in measurement of the time period $T$ of oscillation of the spring. As the time period appears as $T^2$ in Eq. (E 10.5), a small uncertainty in the measurement of $T$ would result in appreciable error in $T^2$, thereby significantly affecting the result. A stop-watch with accuracy of 0.1s may be preferred.
2. Some personal error is always likely to occur in measurement of time due to delay in starting or stopping the watch.
3. Sometimes air currents may affect the oscillations thereby affecting the time period. The time period of oscillation may also get affected if the load is released with a jerk. Take special care that the load while being taken to one side (upwards or downwards) of the rest (or mean) position, is released very gently.
4. The load attached to the spring executes to and fro motion (in SHM) about the mean, equilibrium position. Eqs. (E 10.1) and (E 10.2) hold true for small amplitude of oscillations or small extensions of the spring within the elastic limit (Hook's law). Take care that initially the load is pulled only through a small distance before being released gently to let it oscillate vertically.
5. Oscillations of the helical spring are not likely to be absolutely undamped. Buoyancy of air and viscous drag due to it may slightly increase the time period of the oscillations. The effect can be greatly reduced by taking a small and stiff spring of high density material (such as steel/brass).
6. A rigid support is required for suspending the helical spring. The slotted weights may not have exactly the same mass as engraved on them. Some error in the time period of its oscillation is likely to creep in due to yielding (sometimes) of the support and inaccuracy in the accepted value of mass of load.

## SELF-ASSESSMENT

1. Two springs A (soft) and B (stiff), loaded with the same mass on their hangers, are suspended one by one from the same rigid support. They are set into vertical oscillations at different times, and the time period of their oscillations are noted. In which spring will the oscillations be slower?

2. You are given six known masses ($m_1$, $m_2$ ..., $m_6$), a helical spring and a stop-watch. You are asked to measure time periods ($T_1$, $T_2$, ..., $T_6$) of oscillations corresponding to each mass when it is suspended from the given helical spring.

   (a) What is the shape of the curve you would expect by using Eq. (E 10.2) and plotting a graph between load of mass $m$ along x-axis and $T^2$ on y-axis?

   (b) Interpret the slope, the x-and y-intercepts of the above graph, and hence find (i) spring constant $K$ of the helical spring, and (ii) its effective mass $m_o$.

   [Hint: (a) Eq. (E 10.2), rewritten as: $T^2 = (4\pi^2/K)\, m + (4\pi^2/K)\, m_o$, is similar to the equation of a straight line: $y = mx + c$, with $m$ as the slope of the straight line and $c$ the intercept on y–axis. The graph between $m$ and $T^2$ is expected to be a straight line AB, as shown in Fig. E 10.2. From the above equations given in (a):

   Intercept on y–axis (OD), $c = (4\pi^2/K)\, m_o$; ($x = 0$, $y = c$)

   Intercept on x-axis (OE), $c' = -c/m' = -m_o$; ($y = 0$, $x = -c/m'$)

   Slope, $m' = \tan\theta = OD/OE = c/c' = -c/m_o = (4\pi^2/K)$]

## SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Take three springs with different spring constants $K_1$, $K_2$, $K_3$ and join them in series as shown in Fig. E. 10.3. Determine the time period of oscillation of combined spring and check the relation between individual spring constant and combined system.
2. Repeat the above activity with the set up shown in Fig. E. 10.4 and find out whether there is any difference in the time period and spring constant between the two set ups?
3. What is the physical significance of spring constant 20.5 $Nm^{-1}$?
4. If possible, measure the mass of the spring. Is this related to the effective mass $m_o$?

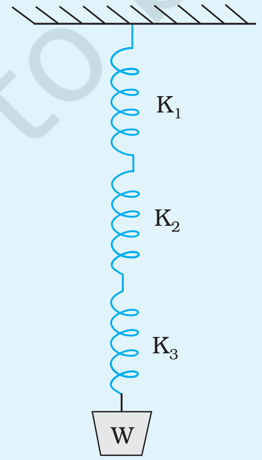



***Fig. E 10.3:*** *Springs joined in series*

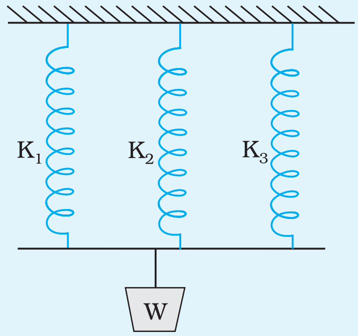



***Fig. E 10.4:*** *Springs joined in parallel*

# EXPERIMENT 11

## AIM

To study the variation in volume ($V$) with pressure ($P$) for a sample of air at constant temperature by plotting graphs between $P$ and $V$, and between $P$ and $\frac{1}{V}$.

## APPARATUS AND MATERIAL REQUIRED

Boyle's law apparatus, Fortin's Barometer, Vernier Callipers, thermometer, set square and spirit level.

## DESCRIPTION AND APPARATUS

The Boyle's law apparatus consists of two glass tubes about 25 cm long and 0.5 cm in diameter (Fig. E11.1). One tube AB is closed at one end while the other CD is open. The two tubes are drawn into a fine opening at the other end (B and D). The ends B and D are connected by a thick walled rubber tubing. The glass tube AB is fixed vertically along the metre scale. The other tube CD can be moved vertically along a vertical rod and may be fixed to it at any height with the help of screw S.

The tube CD, AB and rubber tubing are filled with mercury. The closed tube AB traps some air in it. The volume of air is proportional to the length of air column as it is of uniform cross section.

The apparatus is fixed on a horizontal platform with a vertical stand. The unit is provided with levelling screws.

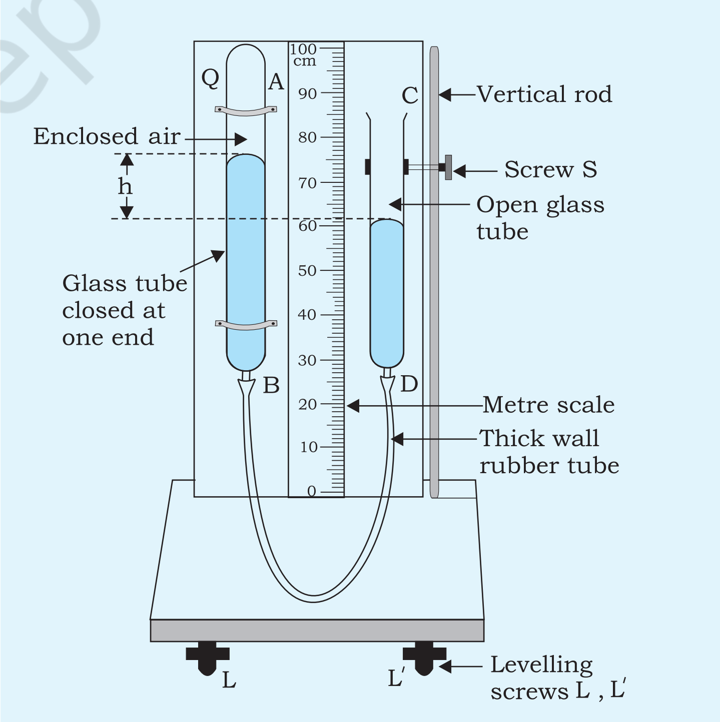



***Fig. E11.1:*** *Boyle's law apparatus*

# PROCEDURE

(a) Measurement of Pressure:

The pressure of the enclosed air in tube AB is measured by noting the difference ($h$) in the mercury levels ($X$ and $Y$) in the two tubes AB and CD (Fig. E11.2). Since liquid in interconnected vessels have the same pressure at any horizontal level,

$P$ (Pressure of enclosed air) = $H \pm h$ (E 11.1)

where $H$ is the atmospheric pressure.

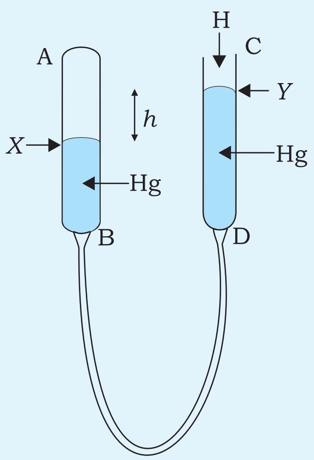



***Fig. E 11.2 :*** *Pressure of air in tube AB = H + h*

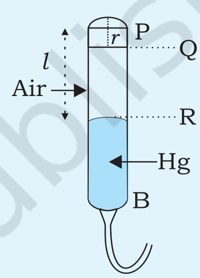



***Fig. E 11.3 :*** *Volume of trapped air in tube AB*

(b) Measurement of volume of trapped air

In case the closed tube is not graduated.

Volume of air in tube

= Volume of air in length PR – Volume of air in curved portion PQ

Let $r$ be the radius of the tube

Volume of curved portion = volume of the hemisphere of radius $r$

$$= \frac{1}{2} \times \frac{4}{3} \pi r^3 = \frac{2}{3} \pi r^3$$

Volume of PQ = $\pi r^2 \times r = \pi r^3$

$$\text{error in volume} = \pi r^3 - \frac{2}{3} \pi r^3 = \frac{1}{3} \pi r^3$$

$$\text{resulting error in length} = \frac{1}{3} \pi r^3 / \pi r^2 = \frac{1}{3} r$$

correction in length $= -\frac{1}{3}r = -\frac{1}{3}PQ$ (E 11.2)

This should be subtracted from the measured length $l$.

Boyle's law: At a constant temperature, the pressure exerted by an enclosed mass of gas is inversely proportional to its volume.

$$P \alpha \frac{1}{V}$$

or $\quad PV = \text{constant}$ (E 11.3)

Hence the $P - V$ graph is a curve while that of $P - \frac{1}{V}$ is a straight line.

(c) Measurement of volume of air for a given pressure.

1. Note the temperature of the room with a thermometer.
2. Note the atmospheric pressure using Fortin's Barometer (Project P-9).
3. Set the apparatus vertically using the levelling screws and spirit level.
4. Slide the tube CD to adjust the mercury level at the same level as in AB. Use set square to read the upper convex meniscus of mercury.
5. Note the reading of the metre scale corresponding to the top end of the closed tube P and that of level Q where its curvature just ends. Calculate $\frac{1}{3}$ PQ and note it.
6. Raise CD such that the mercury level in tubes AB and CD is different. Use the set square to carefully read the meniscus X and Y of mercury in tube AB and CD. Note the difference $h$ in the mercury level.
7. Repeat the adjustment of CD for 5 more values of '$h$'. This should be done slowly and without jerk. Changing the position of CD with respect to AB slowly ensures that there is no change in temperature, otherwise the Boyle's law will not be valid.
8. Use the Vernier Callipers to determine the diameter of the closed tube AB and hence find '$r$', its radius $\frac{1}{3}$ PQ = $\frac{1}{3}r$.
9. Record your observations in the Table E 11.1.
10. Plot graphs (i) P versus V and (ii) P versus $\frac{1}{V}$, interpret the graphs.

## OBSERVATIONS AND CALCULATIONS

1. Room temperature = ... °C.
2. Atmospheric pressure as observed from the Fortins Barometer = ... cm of Hg.
3. For correction in level $l$ due to curved portion of tube AB

   (a) Reading for the top of the closed tube AB (P) = ... cm.

   Reading where the uniform portion of the tube AB begins (or the curved portion ends) (Q) = ... cm.

   Difference (P – Q) = r = ... cm.

   Correction = $\frac{1}{3}r$ = ...

   OR

   (b) Diameter of tube AB = d = ... cm.

   radius $r = \frac{1}{2}d$ = ... cm.

   correction for level $l = \frac{1}{3}r$

## RESULT

1. Within experimental limits, the graph between P and V is a curve.
2. Within experimental limits, the product PV is a constant (from the calculation).

**Table E 11.1 : Measurement of Pressure and Volume of enclosed air**

| S. No. | Level of mercury in closed tube AB X (cm of Hg) | Level of mercury in open tube CD Y (cm of Hg) | Pressure difference $h$ = X–Y (cm of Hg) | Pressure of air in AB = H ± h (cm of Hg) | Volume of air XA $\left(l - \frac{1}{3}r\right)$ | $PV$ or P × $l$ | $1/V$ or $\frac{1}{l}$ |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |

**Note:** $H \pm h$ must be considered according to the levels X and Y taking into account whether the pressure of air in AB will be more than atmospheric pressure or less.

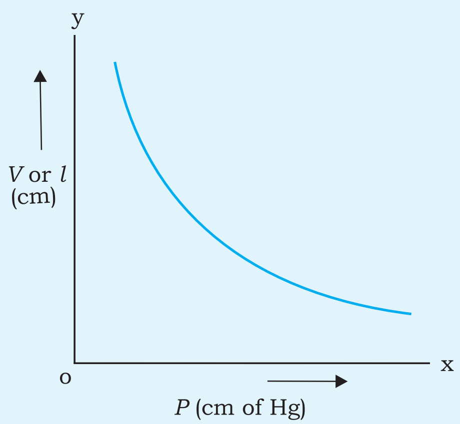



***Fig. E11.4 :*** *Graph between Volume, V and pressure, P*

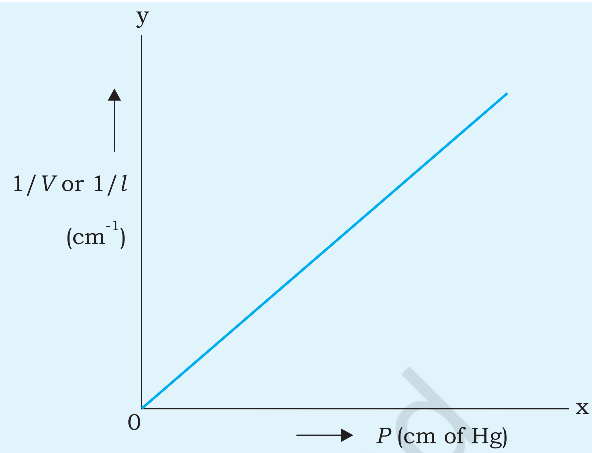



***Fig. E11.5 :*** *Graph between $\frac{1}{V}$ and pressure P*

Note that Fig. E 11.4 shows that the graph between $P$ and $V$ is a curve and that between $P$ and $\frac{1}{V}$ is a straight line (Fig. E 11.5).

3. The graph P and $\frac{1}{V}$ is a straight line showing that the pressure of a given mass of enclosed gas is inversely proportional to its volume at constant temperature.

## PRECAUTIONS

1. The apparatus should be kept covered when not in use.
2. The apparatus should not be shifted in between observations.
3. While measuring the volume of the air, correction for the curved portion of the closed tube should be taken into account.
4. Mercury used should be clean and not leave any trace on the glass. The open tube should be plugged with cotton wool when not in use.
5. The set square should be placed tangential to the upper meniscus of the mercury for determining its level.

## SOURCES OF ERROR

1. The enclosed air may not be dry.
2. Atmospheric pressure and temperature of the laboratory may change during the course of the experiment.

3. The closed end of the tube AB may not be hemispherical.
4. The mercury may be oxidised due to exposure to atmosphere.

## DISCUSSION

1. The apparatus should be vertical to ensure that the difference in level ($h$) is accurate.
2. The diameter of the two glass tubes may or may not be the same but the apparatus should be vertical.
3. The open tube CD should be raised or lowered gradually to ensure that the temperature of the enclosed air remains the same.
4. The readings should be taken in order (above and below the atmospheric pressure). This ensures wider range of consideration, also if they are taken slowly the atmospheric pressure and temperature over the duration of observation remain the same. So time should not be wasted.
5. Why should the upper meniscus of mercury in the two tubes recorded carefully using a set square?

## SELF ASSESSMENT

1. Plot $\frac{1}{V}$ versus '$h$' graph and determine the value of $\frac{1}{V}$ when $h = 0$. Compare this to the value of atmospheric pressure. Give a suitable explanation for your result.
2. Comment on the two methods used for estimation of the volume of the curved portion of the closed tube. What are the assumptions made for the two methods?
3. If the diameter of tube AB is large, why would the estimation of the curved portion be unreliable?
4. The apparatus when not in use should be kept covered to avoid contamination of mercury in the open tube. How will oxidation of mercury affect the experiment?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Tilt apparatus slightly and note the value of '$h$' for two or three values of X and Y.
2. Take a glass U tube. Fill it with water. Pour oil in one arm. Note the difference in level of water, level of oil and water in the two arms. Deduce the density of oil. What role does atmospheric pressure play in this experiment?

# EXPERIMENT 12

## AIM

To determine the surface tension of water by capillary rise method.

## APPARATUS AND MATERIAL REQUIRED

A glass/plastic capillary tube, travelling microscope, beaker, cork with pin, clamps and stand, thermometer, dilute nitric acid solution, dilute caustic soda solution, water, plumb line.

## PRINCIPLE

When a liquid rises in a capillary tube [Fig. E 12.1], the weight of the column of the liquid of density $\rho$ below the meniscus, is supported by the upward force of surface tension acting around the circumference of the points of contact. Therefore

$2\pi rT = \pi r^2 h\rho g$ (approx) for water

or $T = \dfrac{h\rho gr}{2}$

where $T$ = surface tension of the liquid,

$h$ = height of the liquid column and

$r$ = inner radius of the capillary tube

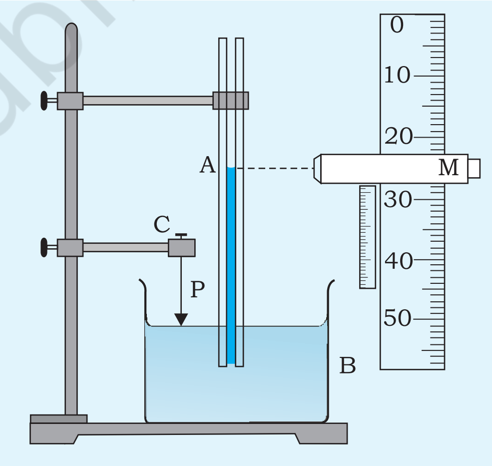



**Fig.E 12.1:** *Rise of liquid in a capillary tube*

## PROCEDURE

1. Do the experiment in a well-lit place for example, near a window or use an incandescent bulb.
2. Clean the capillary tube and beaker successively in caustic soda and nitric acid and finally rinse thoroughly with water.
3. Fill the beaker with water and measure its temperature.
4. Clamp the capillary tube near its upper end, keeping it above the beaker. Set it vertical with the help of a plumbline held near it.

Move down the tube so that its lower end dips into the water in the beaker.

5. Push a pin P through a cork *C*, and fix it on another clamp such that the tip of the pin is just above the water surface as shown in Fig. E 12.1. Ensure that the pin does not touch the capillary tube. Slowly lower the pin till its tip just touches the water surface. This can be done by coinciding the tip of the pin with its image in water.
6. Now focus the travelling microscope M on the meniscus of the water in capillary A, and move the microscope until the horizontal crosswire is tangential to the lowest point of the meniscus, which is seen inverted in M. If there is any difficulty in focussing the meniscus, hold a piece of paper at the lowest point of the meniscus outside the capillary tube and focus it first, as a guide. Note the reading of travelling microscope.
7. Mark the position of the meniscus on the capillary with a pen. Now carefully remove the capillary tube from the beaker, and then the beaker without disturbing the pin.
8. Focus the microscope on the tip of the pin and note the microscope reading.
9. Cut the capillary tube carefully at the point marked on it. Fix the capillary tube horizontally on a stand. Focus the microscope on the transverse cross section of the tube and take readings to measure the internal diameter of the tube in two mutually perpendicular directions.

## OBSERVATIONS

Determination of $h$

Least count (L.C.) of the microscope = ... mm

**Table E 12.1 : Measurement of capillary rise**

| S. No. | Reading of meniscus $h_1$ (cm) | | | Reading of tip of pin touching surface of water $h_2$ (cm) | | | $h = h_1 - h_2$ |
|---|---|---|---|---|---|---|---|
| | M.S.R. $S$ (cm) | V.S.R. $n$ | $h_1 = (S + n \times \text{L.C.})$ | M.S.R. $S'$ (cm) | V.S.R. $n'$ | $h_2 = (S' + n' \times \text{L.C.})$ (cm) | |
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |

**Table E 12.2 : Measurement of diameter of the capillary tube**

| S. No. | Reading along a diameter (cm) | | Diameter $d_1\ (x_2 - x_1)$ | Reading along perpendicular diameter (cm) | | Diameter $d_2\ (y_2 - y_1)$ | Mean diameter $d$ |
|---|---|---|---|---|---|---|---|
| | One end | other end | (cm) | One end | other end | (cm) | $= \frac{d_1 + d_2}{2}$ (cm) |
| 1 | $x_1$ | $x_2$ | | $y_1$ | $y_2$ | | |
| 2 | | | | | | | |
| 3 | | | | | | | |

Mean radius $r$ = ... cm; Temperature of water $\theta$ = ... °C;

Density of water at $0°$ C = ... g cm$^{-3}$

## CALCULATION

Substitute the value of $h$ and $r$ and $\rho g$ in the formula for $T$ and calculate the surface tension.

## RESULT

The surface tension of water at ... °C = ... ± ... Nm$^{-1}$

## PRECAUTIONS

1. To make capillary tube free of contamination, it must be rinsed first in a solution of caustic soda then with dilute nitric acid and finally cleaned with water thoroughly.
2. The capillary tube must be kept vertical while dipping it in water.
3. To ensure that capillary tube is sufficiently wet, raise and lower water level in container by lifting or lowering the beaker. It should have no effect on height of liquid level in the capillary tube.
4. Water level in the capillary tube should be slightly above the edge of the beaker/dish so that the edge does not obstruct observations.
5. Temperature should be recorded before and after the experiment.
6. Height of liquid column should be measured from lowest point of concave meniscus.

## SOURCES OF ERROR

1. Inserting dry capillary tube in the liquid can cause gross error in the measurement of surface tension as liquid level in capillary tube may not fall back when the level in container is lowered.

2. Surface tension changes with impurities and temperature of the liquid.

3. Non-vertical placement of the capillary tube may introduce error in the measurement of height of the liquid column in the tube.

4. Improper focussing of meniscus in microscope could cause an error in measurement of the height of liquid column in the capillary tube.

## DISCUSSION

1. In a fine capillary tube, the meniscus surface may be considered to be semispherical and the weight of the liquid above the lowest point of the meniscus as $\frac{1}{3}\rho r^3 \pi g$ . Taking this into account, the formula for surface tension is modified to $T = \frac{1}{2}\rho gr\left(h + \frac{r}{3}\right)$. More precise calculation of surface tension can be done using this formula.

2. If the capillary is dry from inside the water that rises to a certain height in it will not fall back, so the capillary should be wet from inside. To wet the inside of the capillary tube thoroughly, it is first dipped well down in the water and raised and clamped. Alternatively, the beaker may be lifted up and placed down.

## SELF ASSESSMENT

1. Suppose the length of capillary tube taken is less than the height upto which liquid could rise. What do you expect if such a tube is inserted inside the liquid? Explain your answer.

2. Two match sticks are floating parallel and quite close to each other. What would happen if a drop of soap solution or a drop of hot water falls between the two sticks? Explain your answer.



**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Experiment can be performed at different temperatures and effect of temperature on surface tension can be studied.

2. Experiment can be performed by adding some impurities and effect of change in impurity concentration (like adding NaCl or sugar) on surface tension can be studied.

3. Study the effect of inclination of capillary tube on height of liquid rise in the capillary tube.

# EXPERIMENT 13

## AIM

To determine the coefficient of viscosity of a given liquid by measuring the terminal velocity of a spherical body.

## APPARATUS AND MATERIAL REQUIRED

A wide bore tube of transparent glass/acrylic (approximately 1.25 m long and 4 cm diameter), a short inlet tube of about 10 cm length and 1 cm diameter (or a funnel with an opening of 1 cm), steel balls of known diameters between 1.0 mm to 3 mm, transparent viscous liquid (castor oil/glycerine), laboratory stand, forceps, rubber bands, two rubber stoppers (one with a hole), a thermometer (0-50 °C), and metre scale.

## PRINCIPLE

When a spherical body of radius $r$ and density $\sigma$ falls freely through a viscous liquid of density $\rho$ and viscosity $\eta$ with terminal velocity $v$, then the sum of the upward buoyant force and viscous drag, force $F$, is balanced by the downward weight of the ball (Fig. E13.1).

= Buoyant force on the ball + viscous force

$$\frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi r^3 \rho g + 6\pi\eta r v \qquad \text{(E 13.1)}$$

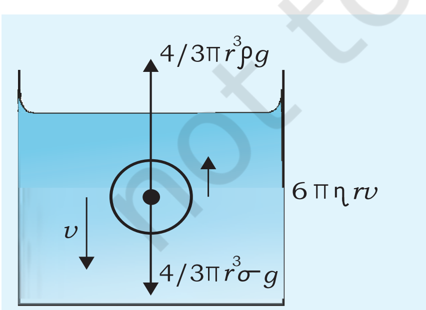



**Fig.E 13.1:** *Forces acting on a spherical body falling through a viscous liquid with terminal velocity*

or $$v = \frac{\frac{4}{3}\pi r^3 (\sigma - \rho) g}{6\pi\eta r} = \frac{2}{q}\frac{r^2 (\sigma - \rho) g}{\eta} \qquad \text{(E 13.2)}$$

where $v$ is the terminal velocity, the constant velocity acquired by a body while moving through viscous fluid under application of constant force.

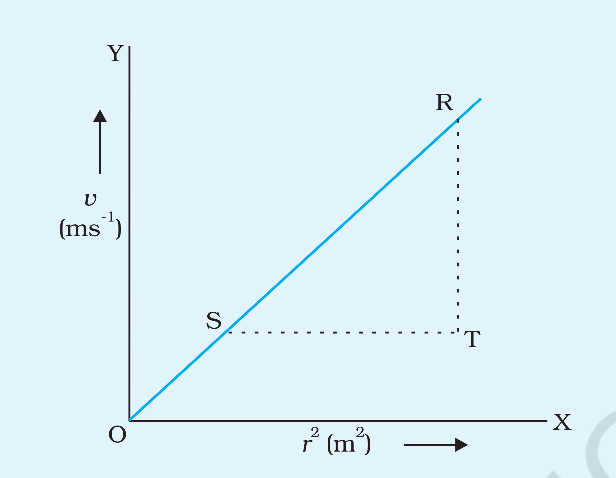
The terminal velocity depends directly on the square of the size (diameter) of the spherical ball. Therefore, if several spherical balls of different radii are made to fall freely through the viscous liquid then a plot of $v$ vs $r^2$ would be a straight line as illustrated in Fig. E 13.2.

The shape of this line will give an average value of $v/r^2$ which may be used to find the coefficient of viscosity $\eta$ of the given liquid. Thus

(E 13.3)

$$\eta = \frac{2}{9} g(\sigma - \rho) . \frac{r^2}{v} = \frac{2}{9} \frac{(\sigma - \rho) g}{(\text{slope of line})}$$

$= \ldots \text{ Nsm}^{-2}$ (poise)




The relation given by Eq. (E 13.3) holds good if the liquid through which the spherical body falls freely is in a cylindrical vessel of radius $R >> r$ and the height of the cylinder is sufficient enough to let the ball attain terminal velocity. At the same time the ball should not come in contact with the walls of the vessel.

## PROCEDURE

***Fig.E 13.2:*** *Graph between terminal velocity v, and square of radius of ball, $r^2$*

1. Find the least count of the stop-watch.
2. Note the room temperature, using a thermometer.
3. Take a wide bore tube of transparent glass/acrylic (of diameter about 4 cm and of length approximately1.25 m). Fit a rubber stopper at one end of the wide tube and ensure that it is airtight. Fill it with the given transparent viscous liquid (say glycerine). Fix the tube vertically in the clamp stand as shown in Fig. E 13.3. Ensure that there is no air bubble inside the viscous liquid in the wide bore tube.
4. Put three rubber bands A, B, and C around the wide bore tube dividing it into four portions (Fig. E 13.3), such that AB = BC, each about 30 cm. The rubber band A should be around 40 cm below the mouth of the wide bore tube (length sufficient to allow the ball to attain terminal velocity).
5. Separate a set of clean and dry steel balls of different radii. The set should include four or five identical steel balls of same known radii ($r_1$). Rinse these balls thoroughly with the experimental viscous liquid (glycerine) in a petridish or a watch glass. Otherwise

these balls may develop air bubble(s) on their surfaces as they enter the liquid column.

6. Fix a short inlet tube vertically at the open end of the wide tube through a rubber stopper fixed to it. Alternately one can also use a glass funnel instead of an inlet tube as shown in Fig. E 13.3. With the help of forceps hold one of the balls of radius $r_1$ near the top of tube. Allow the ball to fall freely. The ball, after passing through the inlet tube, will fall along the axis of the liquid column.

7. Take two stop watches and start both of them simultaneously as the spherical ball passes through the rubber band A. Stop one the watches as the ball passes through the band B. Allow the second stop-watch to continue and stop it when the ball crosses the band C.

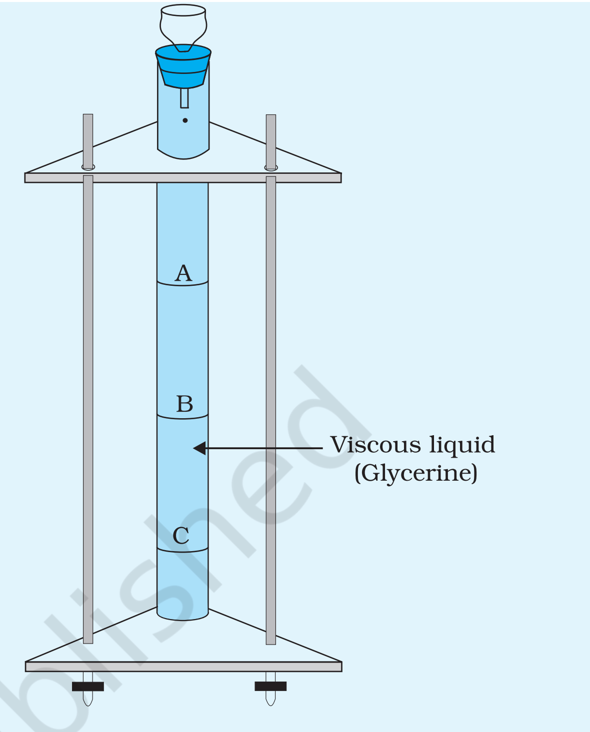



***Fig.E 13.3:*** *Steel ball falling along the axis of the tube filled with a viscous liquid.*

8. Note the times $t_1$ and $t_2$ as indicated by the two stop watches, $t_1$ is then the time taken by the falling ball to travel from A to B and $t_2$ is the time taken by it in falling from A to C. If terminal velocity had been attained before the ball crosses A, then $t_2 = 2\ t_1$. If it is not so, repeat the experiment with steel ball of same radii after adjusting the positions of rubber bands.

9. Repeat the experiment for other balls of different diameters.

10. Obtain terminal velocity for each ball.

11. Plot a graph between terminal velocity, $v$ and square of the radius of spherical ball, $r^2$. It should be a straight line. Find the slope of the line and hence determine the coefficient of viscosity of the liquid using the relation given by Eq. (E 13.3).

## OBSERVATIONS

1. Temperature of experimental liquid (glycerine) $\theta$ = ...°C.
2. Density of material of steel balls $\sigma$= ... kg m$^{-3}$
3. Density of the viscous liquid used in the tube = ... kgm$^{-3}$
4. Density of experimental viscous liquid $\rho$ = ... kg m$^{-3}$

5. Internal diameter of the wide bore tube =... cm = ... m
6. Length of wide bore tube = ... cm = ... m
7. Distance between A and B = ... cm = ... m
8. Distance between B and C = ... cm = ... m

   Average distance $h$ between two consecutive rubber bands = ... cm = ... m
9. Acceleration due to gravity at the place of experiment, = ... gms$^{-2}$
10. Least count of stop-watch = ... s

**Table E 13.1: Measurement of time of fall of steel balls**

| S. No. | Diameter and radio of spherical balls | | Square of the radius of the balls $r^2$ (m$^2$) | Time taken for covering distance $h$ = ... cm between rubber bands | | | | Terminal Velocity $v = \frac{h}{t}$ (m$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | $d$ (cm) | $r=d/2$ (m) | | A and B $t_1$ (s) | A and C $t_2$ (s) | B and C $t_3=t_2-t_1$ (s) | Mean time $t = \frac{t_1+t_3}{2}$ (s) | |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |

## GRAPH

Plot a graph between $r^2$ and $v$ taking $r^2$ along $x$-axis and $v$ along $y$-axis. This graph will be similar to that shown in Fig. E 13.2.

Slope of line $\frac{v}{r^2} = \frac{\text{RT}}{\text{ST}}$

So $\eta = \frac{2}{9}\frac{r^2(\sigma-\rho)g}{(\text{slope of line})}$

Error $\frac{\Delta\eta}{\eta} = \frac{2\Delta r}{r} + \frac{\Delta\text{slope}}{\text{slope}}$

Standard value of $\eta$ = ... Nsm$^{-2}$

% error in $\eta$ = ... %

## RESULT

The coefficient of viscosity of the given viscous liquid at temperature $\theta$ °C = ... ± ... Nsm$^{-2}$

## PRECAUTIONS AND SOURCES OF ERROR

1. In order to minimise the effects, although small, on the value of terminal velocity (more precisely on the value of viscous drag, force F), the radius of the wide bore tube containing the experimental viscous liquid should be much larger than the radius of the falling spherical balls.
2. The steel balls should fall without touching the sides of the tube.
3. The ball should be dropped gently in the tube containing viscous/ liquid.

## DISCUSSION

1. Ensure that the ball is spherical. Otherwise formula used for terminal velocity will not be valid.
2. Motion of falling ball must be translational.
3. Diameter of the wide bore tube should be much larger than that of the spherical ball.

## SELF ASSESSMENT

1. Do all the raindrops strike the ground with the same velocity irrespective of their size?
2. Is Stokes' law applicable to body of shapes other than spherical?
3. What is the effect of temperature on coefficient of viscosity of a liquid?



**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Value of $\eta$ can be calculated for steel balls of different radii and compared with that obtained from the experiment.
2. To find viscosity of mustard oil [**Hint:** Set up the apparatus and use mustard oil instead of glycerine in the wide bore tube].
3. To check purity of milk [**Hint:** Use mustard oil in the tall tube. Take an eye dropper, fill milk in it. Drop one drop of milk in the oil at the top of the wide bore tube and find its terminal velocity. Use the knowledge of coefficient of viscosity of mustard oil to calculate the density of milk].
4. Study the effect of viscosity of water on the time of rise of air bubble [**Hint:** Use the bubble maker used in an aquarium. Place it in the wide bore tube. Find the terminal velocity of rising air bubble].

# EXPERIMENT 14

## AIM

To study the relationship between the temperature of a hot body and time by plotting a cooling curve.

## APPARATUS AND MATERIAL REQUIRED

Newton's law of cooling apparatus that includes a copper calorimeter with a wooden lid having two holes for inserting a thermometer and a stirrer and an open double – walled vessel, two celsius thermometers (each with least count 0.5 °C or 0.1 °C), a stop clock/watch, a heater/burner, liquid (water), a clamp stand, two rubber stoppers with holes, strong cotton thread and a beaker.

## DESCRIPTION OF APPARATUS

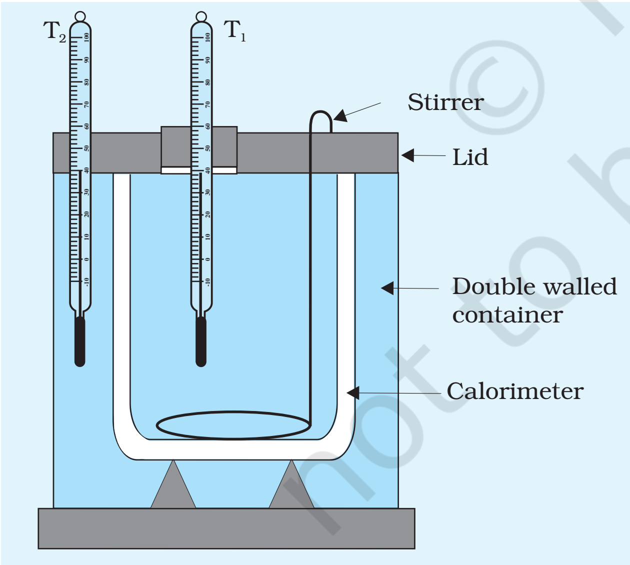



***Fig.E 14.1:*** *Newton's law of cooling apparatus*

As shown in Fig. E 14.1, the law of cooling apparatus has a double walled container, which can be closed by an insulating lid. Water filled between double walls ensures that the temperature of the environment surrounding the calorimeter remains constant. Temperature of the liquid and the calorimeter also remains constant for a fairly long period of time so that temperature measurement is feasible. Temperature of water in calorimeter and that of water between double walls of container is recorded by two thermometers.

## THEORY

The rate at which a hot body loses heat is directly proportional to the difference between the temperature of the hot body and that of its surroundings and depends on the nature of material and the surface area of the body. This is Newton's law of cooling.

For a body of mass $m$ and specific heat $s$, at its initial temperature $\theta$ higher than its surrounding's temperature $\theta_o$, the rate of loss of heat

is $\frac{dQ}{dt}$, where d$Q$ is the amount of heat lost by the hot body to its surroundings in a small interval of time.

Following Newton's law of cooling we have

Rate of loss of heat, $\frac{dQ}{dt} = -k\ (\theta - \theta_o)$ (E 14.1)

Also $\frac{dQ}{dt} = ms\ \frac{d\theta}{dt}$ (E 14.2)

Using Eqs. (E 14.1) and (E 14.2), the rate of fall of temperature is given by

$$\frac{d\theta}{dt} = -\frac{k}{ms}\ (\theta - \theta_o) \qquad \text{(E 14.3)}$$

where $k$ is the constant of proportionality and $k' = k/ms$ is another constant (The term $ms$ also includes the water equivalent of the calorimeter with which the experiment is performed). Negative sign appears in Eqs. (E 14.2) and (E 14.3) because loss of heat implies temperature decrease. Eq. (E 14.3) may be re written as

$$d\theta = -k'\ (\theta - \theta_o)\, dt$$

On integrating, we get

$$\int \frac{d\theta}{\theta - \theta_o} = -k' \int dt$$

or $\ln\ (\theta - \theta_o) = \log_e\ (\theta - \theta_o) = -k'\ t + c$

or $\ln\ (\theta - \theta_o) = 2.303\ \log_{10} (\theta - \theta_o) = -k'\ t + c$ (E 14.4)

where c is the constant of integration.

Eq. (E 14.4) shows that the shape of a plot between $\log_{10} (\theta - \theta_o)$ and $t$ will be a straight line.

## PROCEDURE

1. Find the least counts of thermometers $T_1$ and $T_2$. Take some water in a beaker and measure its temperature (at room temperature $\theta_o$) with one (say $T_1$) of the thermometers.
2. Examine the working of the stop-watch/clock and find its least count.
3. Pour water into the double- walled container (enclosure) at room temperature. Insert the other thermometer $T_2$ in water contained in it, with the help of the clamp stand.
4. Heat some water separately to a temperature of about 40 °C above the room temperature $\theta_o$. Pour hot water in calorimeter up to its top.

5. Put the calorimeter, with hot water, back in the enclosure and cover it with the lid having holes. Insert the thermometer $T_1$ and the stirrer in the calorimeter through the holes provided in the lid, as shown in Fig. E14.1.

6. Note the initial temperature of the water between enclosure of double wall with the thermometer $T_2$, when the difference of readings of two thermometers $T_1$ and $T_2$ is about 30 °C. Note the initial reading of the thermometer $T_1$.

7. Keep on stirring the water gently and constantly. Note the reading of thermometer $T_1$, first after about every half a minute, then after about one minute and finally after two minutes duration or so.

8. Keep on simultaneously noting the reading of the stop-watch and that of the thermometer $T_1$, while stirring water gently and constantly, till the temperature of water in the calorimeter falls to a temperature of about 5 °C above that of the enclosure. Note the temperature of the enclosure, by the thermometer $T_2$.

9. Record observations in tabular form. Find the excess of temperature $(\theta - \theta_o)$ and also $\log_{10} (\theta - \theta_o)$ for each reading, using logarithmic tables. Record these values in the corresponding columns in the table.

10. Plot a graph between time t, taken along x-axis and $\log_{10} (\theta - \theta_o)$ taken along y-axis. Interpret the graph.

## OBSERVATIONS

Least count of both the identical thermometers = ... °C

Least count of stop-watch/clock = ... s

Initial temperature of water in the enclosure $\theta_1$ = ... °C

Final temperature of water in the enclosure $\theta_2$ = ... °C

Mean temperature of the water in the enclosure $\theta_o = (\theta_1 + \theta_2)/2$ = ... °C

**Table E 14.1: Measuring the change in temperature of water with time**

| S. No. | Time (*t*) (*s*) | Temperature of hot water $\theta$ °C | Excess Temperature of hot water $(\theta - \theta_0)$ °C | $\log_{10} (\theta - \theta_0)$ |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| . | | | | |
| . | | | | |
| 20 | | | | |

## PLOTTING GRAPH

(i) Plot a graph between $(\theta - \theta_o)$ and $t$ as shown in Fig. E 14.2 taking $t$ along x-axis and $(\theta - \theta_o)$ along y-axis. This is called cooling curve.

(ii) Also plot a graph between $\log_{10}(\theta - \theta_o)$ and time $t$, as shown in Fig. E 14.3 taking time $t$ along x-axis and $\log_{10}(\theta - \theta_o)$ along y-axis. Choose suitable scales on these axes. Identify the shape of the cooling curve and the other graph.

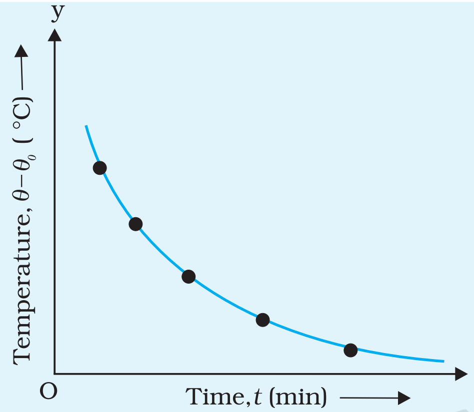



**Fig.E 14.2:** *Graph between $(\theta - \theta_o)$ and t for cooling*

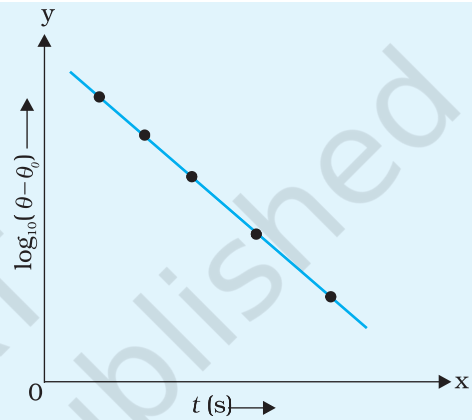



**Fig.E 14.3:** *Graph between $\log_{10}(\theta - \theta_o)$ and t*

## RESULT

The cooling curve is an exponential decay curve (Fig. E 14.2). It is observed from the graph that the logarithm of the excess of temperature of hot body over that of its surroundings varies linearly with time as the body cools.

## PRECAUTIONS

1. The water in the calorimeter should be gently stirred continuously.
2. Ideally the space between the double walls of the surrounding vessel should be filled with flowing water to make it an enclosure having a constant temperature.
3. Make sure that the openings for inserting thermometers are air tight and no heat is lost to the surroundings through these.
4. The starting temperature of water in the calorimeter should be about 30°C above the room temperature.

## SOURCES OF ERROR

1. Some personal error is always likely to be involved due to delay in starting or stopping the stop-watch. Take care in starting and stopping the stop-watch.

2. The accuracy of the result depends mainly on the simultaneous measurement of temperature of hot water (decrease in temperature being fast in the beginning and then comparatively slower afterwards) and the time. Take special care while reading the stop-watch and the thermometer simultaneously.

3. If the opening for the thermometer is not airtight, some loss of heat can occur.

4. The temperature of the water in enclosure is not constant.

## DISCUSSION

Each body radiates heat and absorbs heat radiated by the other. The warmer one (here the calorimeter) radiates more and receives less. Radiation by surface occurs at all temperatures. Higher the temperature difference with the surroundings, higher is rate of heat radiation. Here the enclosure is at a lower temperature so it radiates less but receives more from the calorimeter. So, finally the calorimeter dominates in the process.

## SELF ASSESSMENT

1. State Newton's law of cooling and express this law mathematically.

2. Does the Newton's law of cooling hold good for all temperature differences?

3. How is Newton's law of cooling different from Stefan's law of heat radiation?

4. What is the shape of cooling curve?

5. Find the specific heat of a solid/liquid using Newton's law of cooling apparatus.

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Find the slope and intercept on y-axis of the straight line graph (Fig. E 14.2) you have drawn. Determine the value of constant $k$ and the constant of integration $c$ from this graph.

   [**Hint:** Eq. (E 14.4) is similar to the equation of a straight line: y = $m'$ x + $c'$, with $m'$ as the slope of the straight line and $c'$ the intercept on y-axis. It is clear $m' = k'/2.303$ and $c' = c' \times 2.303$.]

2. The cooling experiment is performed with the calorimeter, filled with same volume of water and turpentine oil successively, by maintaining the same temperature difference between the calorimeter and the surrounding enclosure. What ratio of the rates of heat loss would you expect in this case?

# EXPERIMENT 15

## AIM

(i) To study the relation between frequency and length of a given wire under constant tension using a sonometer.

(ii) To study the relation between the length of a given wire and tension for constant frequency using a sonometer.

## APPARATUS AND MATERIAL REQUIRED

Sonometer, six tuning forks of known frequencies, metre scale, rubber pad, paper rider, hanger with half-kilogram weights, wooden bridges.

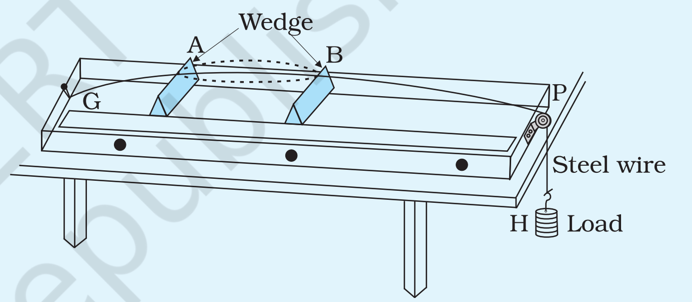



***Fig. E 15.1:*** *A Sonometer*

**SONOMETER**

It consists of a long sounding board or a hollow wooden box W with a peg G at one end and a pulley at the other end as shown in Fig E 15.1. One end of a metal wire S is attached to the peg and the other end passes over the pulley P. A hanger H is suspended from the free end of the wire. By placing slotted weights on the hanger tension is applied to the wire. By placing two bridges A and B under the wire, the length of the vibrating wire can be fixed. Position of one of the bridges, say bridge A is kept fixed so that by varying the position of other bridge, say bridge B, the vibrating length can be altered.

## PRINCIPLE

The frequency $n$ of the fundamental mode of vibration of a string is given by

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \qquad \text{(E 15.1)}$$

where $m$ = mass per unit length of the string

$l$ = length of the string between the wedges

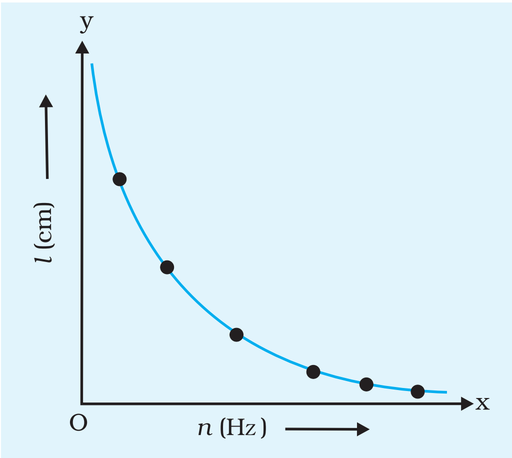



*Fig. E 15.2: Variation of resonant length with frequency of tuning fork*

$T$ = Tension in the string (including the weight of the hanger) = $Mg$

$M$ = mass suspended, including the mass of the hanger

(a) For a given $m$ and fixed $T$,

$$n \, \alpha \frac{1}{l} \quad \text{or} \quad n\,l = \text{constant.}$$

(b) If frequency $n$ is constant, for a given wire ($m$ is constant),

$$\frac{\sqrt{T}}{l} \text{ is constant. That is } l^2 \propto T.$$

### *(i) Variation of frequency with length*

## PROCEDURE

1. Set up the sonometer on the table and clean the groove on the pully to ensure that it has minimum friction. Stretch the wire by placing a suitable load on the hanger.
2. Set a tuning fork of frequency $n_1$ into vibrations by striking it against the rubber pad and hold it near one of your ears. Pluck the sonometer wire and compare the two sounds, one produced by the tuning fork and the other by the plucked wire. Make a note of difference between the two sounds.
3. Adjust the vibrating length of the wire by sliding the bridge B till the two sounds appear alike.
4. For final adjustment, place a small paper rider R in the middle of wire AB. Sound the tuning fork and place its shank stem on the bridge A or on the sonometer box. Slowly adjust the position of bridge B till the paper rider is agitated violently, which indicates resonance.

   The length of the wire between A and B is the resonant length such that its frequency of vibration of the fundamental mode equals the frequency of the tuning fork. Measure this length with the help of a metre scale.
5. Repeat the above procedures for other five tuning forks keeping the load on the hanger unchanged. Plot a graph between $n$ and $l$ (Fig. E 15.2)
6. After calculating frequency, $n$ of each tuning fork, plot a graph between $n$ and $1/l$ where $l$ is the resonating length as shown in Fig. E 15.3.

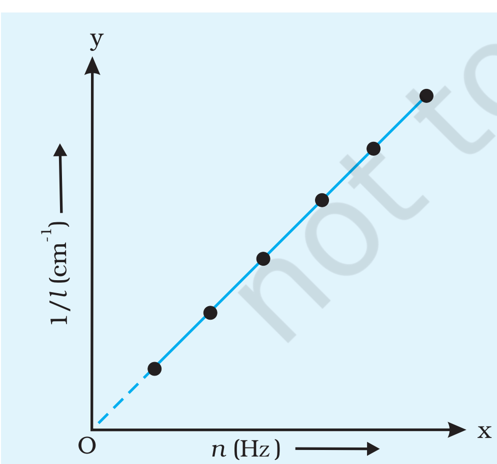



*Fig. E 15.3: Variation of $1/l$ with $n$*

## OBSERVATIONS (A)

Tension (constant) on the wire (weight suspended from the hanger including its own weight) $T = \ldots N$

**Table E 15.1: Variation of frequency with length**

| Frequency $n$ of tuning fork (Hz) | $n_1$ | $n_2$ | $n_3$ | $n_4$ | $n_5$ | $n_6$ |
|---|---|---|---|---|---|---|
| Resonating length $l$ (cm) | | | | | | |
| $\frac{1}{l}$ (cm$^{-1}$) | | | | | | |
| $nl$ (Hz cm) | | | | | | |

## CALCULATIONS AND GRAPH

Calculate the product $nl$ for each fork. and, calculate the reciprocals, $\frac{1}{l}$ of the resonating lengths $l$. Plot $\frac{1}{l}$ *vs* $n$, taking $n$ along $x$ axis and $\frac{1}{l}$ along $y$ axis, starting from zero on both axes. See whether a straight line can be drawn from the origin to lie evenly between the plotted points.

## RESULT

Check if the product $n\,l$ is found to be constant and the graph of $\frac{1}{l}$ *vs* $n$ is also a straight line. Therefore, for a given tension, the resonant length of a given stretched string varies as reciprocal of the frequency.

## DISCUSSION

1. Error may occur in measurement of length $l$. There is always an uncertainty in setting the bridge in the final adjustment.
2. Some friction might be present at the pulley and hence the tension may be less than that actually applied.
3. The wire may not be of uniform cross section.

**(*ii*) *Variation of resonant length with tension for constant frequency***

1. Select a tuning fork of a certain frequency (say 256 *Hz*) and hang a load of 1kg from the hanger. Find the resonant length as before.

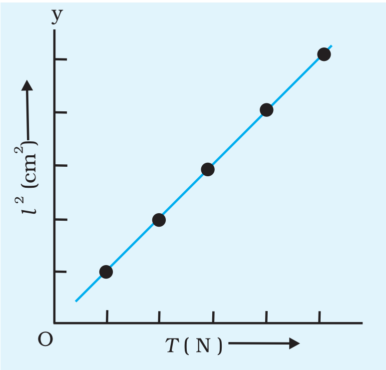



***Fig. E 15.4:*** *Graph between $l^2$ and T*

2. Increase the load on the hanger in steps of 0.5 kg and each time find the resonating length with the same tuning fork. Do it for at least four loads.
3. Record your observations.
4. Plot graph between $l^2$ and T as shown in Fig. E 15.4.

## OBSERVATIONS (B)

Frequency of the tuning fork = ... Hz

**Table E 15.2: Variation of resonant length with tension**

| | | | | | |
|---|---|---|---|---|---|
| Tension applied $T$ (including weight of the hanger) (N) | | | | | |
| Resonating length $l$ of the wire | | | | | |
| $l^2$ (cm$^2$) | | | | | |
| $T/l^2$ (N cm$^{-2}$) | | | | | |

## CALCULATIONS AND GRAPH

Calculate the value of $T/l^2$ for the tension applied in each case. Alternatively, plot a graph of $l^2$ *vs* $T$ taking $l^2$ along $y$-axis and $T$ along the $x$-axis.

## RESULT

It is found that value of $T/l^2$ is constant within experimental error. The graph of $l^2$ *vs* $T$ is found to be a straight line. This shows that

$l^2 \propto T$ or $l \propto \sqrt{T}$ .

Thus, the resonating length varies as square root of tension for a given frequency of vibration of a stretched string.

## PRECAUTIONS

1. Pulley should be frictionless ideally. In practice friction at the pulley should be minimised by applying grease or oil on it.
2. Wire should be free from kinks and of uniform cross section, ideally. If there are kinks, they should be removed by stretching as far as possible.

3. Bridges should be perpendicular to the wire, its height should be adjustes so that a node is formed at the bridge.
4. Tuning fork should be vibrated by striking its prongs against a soft rubber pad.
5. Load should be removed after the experiment.

## SOURCES OF ERROR

1. Pulley may not be frictionless.
2. Wire may not be rigid and of uniform cross section.
3. Bridges may not be sharp.

## DISCUSSION

1. Error may occur in measurement of length $l$. There is always an uncertainty in setting the bridge in the final adjustment.
2. Some friction might be present at the pulley and hence the tension may be less than that actually applied.
3. The wire may not be of uniform cross section.
4. Care should be taken to hold the tuning fork by the shank only.

## SELF ASSESSMENT

1. What is the principle of superposition of waves?
2. What are stationary waves?
3. Under what circumstances are stationary waves formed?
4. Identify the nodes and antinodes in the string of your sonometer.
5. What is the ratio of the first three harmonics produced in a stretched string fixed at two ends?
6. Keeping material of wire and tension fixed, how will the resonant length change if the diameter of the wire is increased?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Take wires of the same material but of three different diameters and find the value of $l$ for each of these for a given frequency, $n$ and tension, $T$.
2. Plot a graph between the value of $m$ and $\frac{1}{l^2}$ obtained, in 1 above, with $m$ along X axis.
3. Pluck the string of an stringed musical instrument like a sitar, voilin or guitar with different lengths of string for same tension or same length of string with different tension. Observe how the frequency of the sound changes.

# EXPERIMENT 16

## AIM

To determine the velocity of sound in air at room temperature using a resonance tube.

## APPARATUS AND MATERIAL REQUIRED

Resonance tube apparatus, a tuning fork of known frequency (preferably of 480 Hz or 512 Hz), a rubber pad, a thermometer, spirit level, a set-square, beaker and water.

## PRINCIPLE

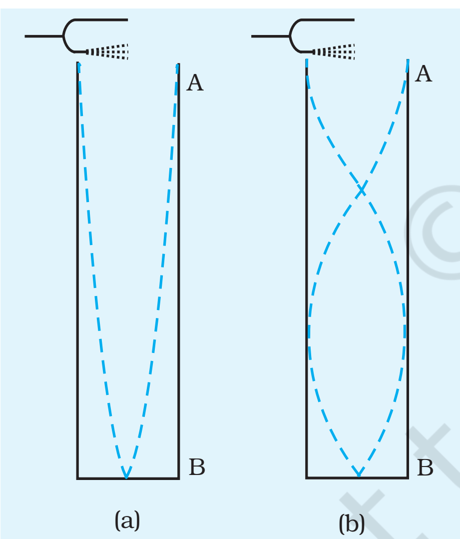



***Fig. E 16.1**: Formation of standing wave in glass tube AB closed at one end*

When a vibrating tuning fork of known frequency $\nu$ is held over the top of an air column in a glass tube AB (Fig. E 16.1), a standing wave pattern could be formed in the tube. Under the right conditions, a superposition between a forward moving and reflected wave occurs in the tube to cause resonance. This gives a very noticeable rise in the amplitude, or loudness, of the sound. In a closed organ pipe like a resonance tube, there is a zero amplitude point at the closed end (Fig. E 16.2). For resonance to occur, a node must be formed at the closed end and an antinode must be formed at the open end. Let the first loud sound be heard at length $l_1$ of the air column [Fig. E 16.2(a)]. That is, when the natural frequency of the air column of length $l_1$ becomes equal to the natural frequency of the tuning fork, so that the air column vibrates with the maximum amplitude. In fact the length of air column vibrating is slightly longer than the length of the air column in tube AB. Thus,

$$\frac{\lambda}{4} = l_1 + e \qquad \text{(E 16.1)}$$

where $e$ (= 0.6 $r$, *where* $r$ = radius of the glass tube) is the end correction for the resonance tube and $\lambda$ is the wave-length of the sound produced by the tuning fork.

Now on further lowering the closed end of the tube AB, let the second resonance position be heard at length $l_2$ of the air column in the tube

[Fig. E 16.2(b)]. This length $l_2$ would approximately be equal to three quarters of the wavelength. That is,

(E 16.2) $$\frac{3\lambda}{4} = l_2 + e$$

Subtracting Eq. (E 16.l) from Eq. (E 16.2) gives

(E. 16.3) $$\lambda = 2\,(l_2 - l_1)$$

Thus, the velocity of sound in air at room temperature ($v = \nu\lambda$) would be $v = 2\nu\,(l_2 - l_1)$.

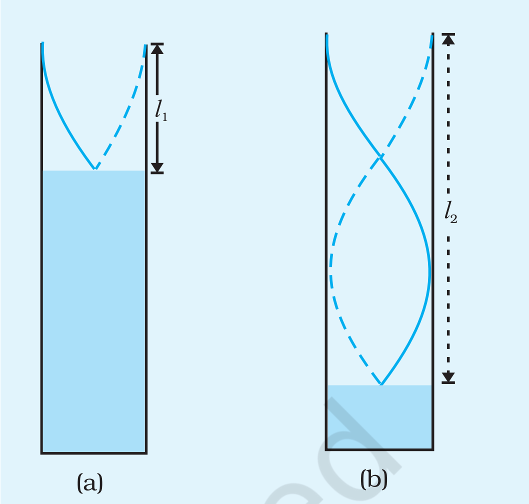



***Fig. E 16.2**: Vibrations in a resonance tube*

## PROCEDURE

**ADJUSTMENT OF RESONANCE TUBE**

The apparatus usually consists of a narrow glass tube about a metre long and 5 cm in diameter, rigidly fixed in its vertical position with a wooden stand. The lower end of this tube is attached to a reservoir by a rubber tube. Using a clamp, the reservoir can be made to slide up or down along a vertical rod. A pinch cock is provided with the rubber tube to keep the water level (or the length of air column) fixed in the tube. A metre scale is also fixed along the tube. The whole apparatus is fixed on a horizontal wooden base that can be levelled using the screws provided at the bottom. Both the reservoir and tube contain water. When reservoir is raised the length of the air column in the tube goes down, and when it is lowered the length of the air column in the tube goes up. Now:–

1. Set the resonance tube vertical with the help of a spirit level and levelling screws provided at the bottom of the wooden base of the apparatus.
2. Note the room temperature with a thermometer.
3. Note the frequency $\nu$ of given tuning fork.
4. Fix the reservoir to the highest point of the vertical rod with the help of clamp.

***De--termination of First Resonance Position***

5. Fill the water in the reservoir such that the level of water in the tube reaches up to its open end.
6. Close the pinch cock and lower down the position of reservoir on the vertical rod.
7. Gently strike the given tuning fork on a rubber pad and put it nearly one cm above the open end of the tube. Keep both the

prongs of the tuning fork parallel to the ground and lying one above the other so that the prongs vibrate in the vertical plane. Try to listen the sound being produced in the tube. It may not be audible in this position.

8. Slowly loosen the pinch cock to let the water level fall in the tube very slowly. Keep bringing the tuning fork near the open end of the resonance tube, notice the increasing loudness of the sound.

9. Repeat steps 7 and 8 till you get the exact position of water level in the tube for which the intensity of sound being produced in the tube is maximum. This corresponds to *the first resonance position or fundamental node,* if the length of air column is minimum. Close the pinch cock at this position and note the position of water level or length $l_1$ of air column in the tube [Fig. E 16.2]. This is the determination of first resonance position while the level of water is falling in the tube.

10. Repeat steps (5) to (9) to confirm the first resonance position.

11. Next find out the first resonance position by gradually raising the level of water in resonance tube, and holding the vibrating tuning fork continuously on top of its open end. Fix the tube at the position where the sound of maximum intensity is heard.

***Determination of Second Resonance Position***

12. Lower the position of the water level further in the resonance tube by sliding down the position of reservoir on the vertical stand and opening the pinch cock till the length of air column in the tube increases about three times of the length $l_1$.

13. Find out the second resonance position and determine the length of air column $l_2$ in the tube with the same tuning fork having frequency $\nu_1$ and confirm the length $l_2$ by taking four readings, two when the level of water is falling and the other two when the level of water is rising in the tube.

14. Repeat steps (5) to (13) with a second tuning fork having frequency $\nu_2$ and determine the first and second resonance positions.

15. Calculate the velocity of sound in each case.

## OBSERVATIONS

1. Temperature of the room $\theta$ = ... °C

2. Frequency of first tuning fork , $\nu_1$ = ... Hz

3. Frequency of second tuning fork, $\nu_2$ = ... Hz

**Table E 16.1: Determination of length of the resonant air columns**

| Frequency of tuning fork used | S. No. | length $l_1$ for the first resonance position of the tube | | | length $l_2$ for the second resonance position of the tube | | |
|---|---|---|---|---|---|---|---|
| | | Water level is falling | Water level is rising | Mean length, $l_1$ cm | Water level is falling | Water level is rising | Mean length, $l_2$ cm |
| $\nu_1$ = ... Hz | 1<br>2 | | | | | | |
| $\nu_2$ = ... Hz | 1<br>2 | | | | | | |

## CALCULATIONS

(i) For first tuning fork having frequency $\nu_1$ = ... Hz

Velocity of sound in air $\upsilon_1 = 2\ \nu_1\ (l_2 - l_1)$ = ... $ms^{-1}$

(ii) For second tuning fork having frequency $\nu_2$ = ... Hz

Velocity of sound in air $\upsilon_2 = 2\nu_2\ (l_2 - l_1)$ = ... $ms^{-1}$

Obtain the mean velocity $\upsilon$ of sound in air.

## RESULT

The velocity of sound $\upsilon$ in air at room temperature is

$$\frac{\upsilon_1 + \upsilon_2}{2} = \ldots\ ms^{-1}$$

## PRECAUTIONS

1. The resonance tube should be kept vertical using the levelling screws.
2. The experiment should be performed in a quiet atmosphere so that the resonance positions may be identified properly.
3. Striking of tuning fork on rubber pad must be done very gently.
4. The lowering and raising of water level in the resonance tube should be done very slowly.
5. The choice of frequencies of the tuning forks being used should be such that the two resonance positions may be achieved in the air column of the resonance tube.
6. The vibrating tuning fork must be kept about 1 cm above the top of the resonance tube. In any case it should not touch the walls of the resonance tube.

7. The prongs of the vibrating tuning fork must be kept parallel to the ground and keeping one over the other so that the vibrations reaching the air inside the tube are vertical.

8. Room temperature during the performance of experiment should be measured two to three times and a mean value should be taken.

## SOURCES OF ERROR

1. The air inside the tube may not be completely dry and the presence of water vapours in the air column may exhibit a higher value of velocity of sound.

2. Resonance tube must be of uniform area of cross-section.

3. There must be no wind blowing in the room.

## DISCUSSION

1. Loudness of sound in second resonance position is lower than the loudness in first resonance. We determine two resonance positions in this experiment to apply end correction. But the experiment can also be conducted by finding first resonance position only and applying end correction in resonating length as $e = 0.6\ r$.

2. For a given tuning fork, change in the resonating length of air coloumn in $2^{nd}$ resonance does not change the frequency, wavelength or velocity of sound. Thus, the second resonance is not the overtone of first resonance.

## SELF ASSESSMENT

1. Is the velocity of sound temperature dependent? If yes, write the relation.

2. What would happen if resonance tube is not vertical?

3. Name the phenomenon responsible for the resonance in this experiment.

4. Write two other examples of resonance of sound from day to day life.

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

1. Calculate the end correction in the resonance tube.

2. Compare the end correction required for the resonance tubes of different diameters and study the relation between the end correction and the diameter of the tube.

3. Perform the same experiment with an open pipe.

# EXPERIMENT 17

## AIM

To determine the specific heat capacity of a given (i) and solid (ii) a liquid by the method of mixtures.

## APPARATUS AND MATERIAL REQUIRED

Copper calorimeter with lid, stirrer and insulating cover (the lid should have provision to insert thermometer in addition to the stirrer), two thermometers (0 °C to 100 °C or 110 °C with a least count of 0.5 °C), a solid, preferably metallic (brass/copper/steel/aluminium) cylinder which is insoluble in given liquid and water, given liquid, two beakers (100 mL and 250 mL), a heating device (heater/hot plate/gas burner); physical balance, spring balance with weight box (including fractional weights), a piece of strong non-flexible thread (25-30 cm long), water, laboratory stand, tripod stand and wire gauze.



## PRINCIPLE / THEORY

For a body of mass $m$ and specific heat $s$, the amount of heat $Q$ lost/gained by it when its temperature falls/rises by $\Delta t$ is given by

$$\Delta Q = ms\,\Delta t \quad \text{(E 17.1)}$$

**Specific heat capacity:** It is the amount of heat required to raise the temperature of unit mass of a substance through 1°C. Its S.I unit is $\text{Jkg}^{-1}\,\text{K}^{-1}$.

**Principle of Calorimetry:** If bodies of different temperatures are brought in thermal contact, the amount of heat lost by the body at higher temperature is equal to the amount of heat gained by the body at lower temperature, at thermal equilibrium, provided no heat is lost to the surrounding.

**(a) Specific heat capacity of given solid by method of mixtures**

## PROCEDURE

1. Set the physical balance and make sure there is no zero error.
2. Weigh the empty calorimeter with stirrer and lid with the physical balance/spring balance. Ensure that calorimeter is clean and dry.

Note the mass $m_1$ of the calorimeter. Pour the given water in the calorimeter. Make sure that the quantity of water taken would be sufficient to completely submerge the given solid in it. Weigh the calorimeter with water along with the stirrer and the lid and note its mass $m_2$. Place the calorimeter in its insulating cover.

3. Dip the solid in water and take it out. Now shake it to remove water sticking to its surface. Weigh the wet solid with the physical balance and note down its mass $m_3$.

4. Tie the solid tightly with the thread at its middle. Make sure that it can be lifted by holding the thread without slipping.

   Place a 250 mL beaker on the wire gauze kept on a tripod stand as shown in the Fig. E 17.1(a). Fill the beaker up to the half with water. Now suspend the solid in the beaker containing water by tying the other end of the thread to a laboratory stand. The solid should be completely submerged in water and should be atleast 0.5 cm below the surface. Now heat the water with the solid suspended in it [Fig. E 17.1 (a)].

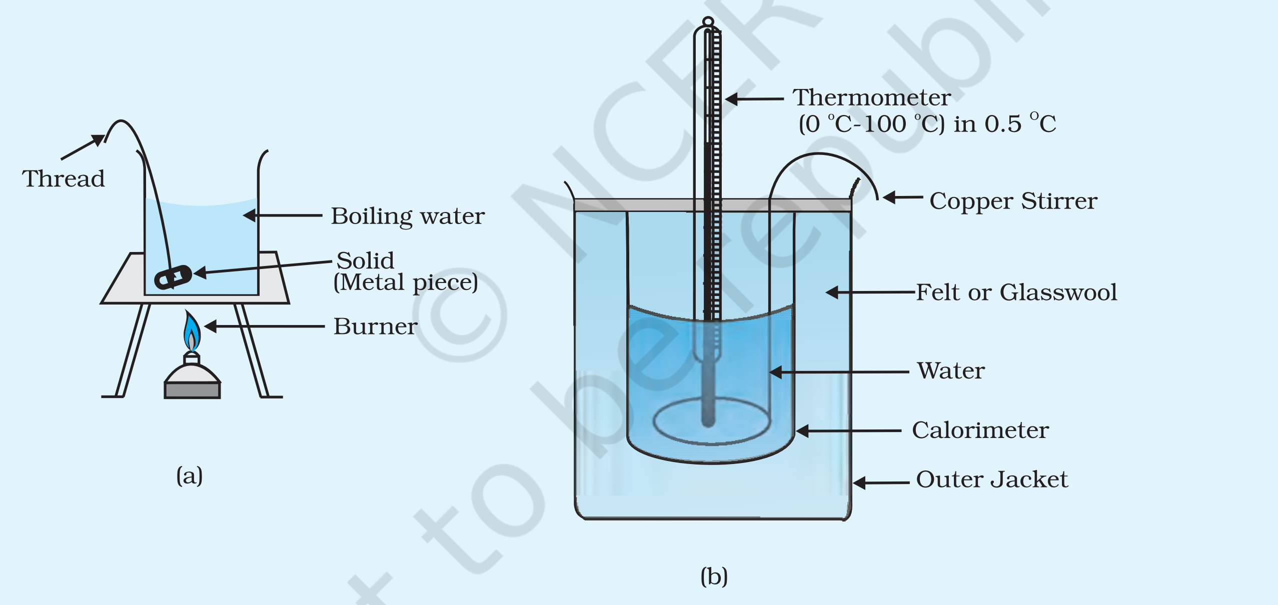



***Fig. E 17.1:*** *Experimental setup for determining specific heat of a given solid*

5. Note the least count of the thermometer. Measure the temperature of the water taken in the calorimeter. Record the temperature $t_1$ of the water.

6. Let the water in the beaker boil for about 5-10 minutes. Now measure the temperature $t_2$ of the water with the other thermometer and record the same. Holding the solid with the thread tied to it,

remove it from the boiling water, shake it to remove water sticking on it and quickly put it in the water in the calorimeter and replace the lid immediately (Fig. E 17.1 (b)). Stir the water with the stirrer. Measure the temperature of the water once equilibrium is attained, that is, temperature of the mixture becomes constant. Record this temperature as $t_3$.

## OBSERVATIONS

Mass of the empty calorimeter with stirrer ($m_1$) = ... g

Mass of the calorimeter with water ($m_2$) = ... g

Mass of solid ($m_3$) = ... g

Initial temperature of the water ($t_1$) = ... °C = ... K

Temperature of the solid in boiling water ($t_2$) = ... °C = ... K

Temperature of the mixture ($t_3$) = ... °C

Specific heat capacity of material of calorimeter $s_1$ = ... J kg$^{-1}$ °C$^{-1}$ (J kg$^{-1}$ K$^{-1}$)

Specific heat capacity of water (s) = ... J kg$^{-1}$ K$^{-1}$

## CALCULATIONS

1. Mass of the water in calorimeter ($m_2 - m_1$) = ... g = ... kg
2. Change in temperature of liquid and calorimeter ($t_3 - t_1$) = ... °C
3. Change in temperature of solid ($t_2 - t_3$) = ... °C

   Heat given by solid in cooling from $t_2$ to $t_3$.

   = Heat gained by liquid in raising its temperature from $t_1$ to $t_3$ + heat gained by calorimeter in raising its temperature from $t_1$ to $t_3$.

   $m_3 s_o (t_2 - t_3) = (m_2 - m_1)\, s\, (t_2 - t_1) + m_1 s_1 (t_3 - t_1)$

   $$s_o = \frac{(m_2 - m_1)\, s\,(t_2 - t_1) + m_1 s_1 (t_3 - t_1)}{m_3 (t_2 - t_3)} = \ldots \text{ J kg}^{-1}\ {}^\circ\text{C}^{-1}$$

**(b) Specific heat capacity of given liquid by method of mixtures**

## PROCEDURE

1. Set the phyiscal balance and make sure there is no zero error.
2. Weigh the empty calorimeter with stirrer and lid with the physical balance/spring balance. Ensure that calorimeter is clean and dry. Note the mass $m_1$ of the calorimeter. Pour the

given liquid in the calorimeter. Make sure that the quantity of liquid taken would be sufficient to completely submerge the solid in it. Weigh the calorimeter with liquid along with the stirrer and the lid and note its mass $m_2$. Place the calorimeter in its insulating cover.

3. Take a metallic cylinder whose specific heat capacity is known. Dip it in water in a container and shake it to remove the water sticking to its surface. Weigh the wet solid with the physical balance and note down its mass $m_3$.

4. Tie the solid tightly with the thread at its middle. Make sure that it can be lifted by holding the thread without slipping.

   Place a 250 mL beaker on the wire gauze kept on a tripod stand as shown in Fig. E 17.1(a). Fill the beaker up to half with water. Now suspend the solid in the beaker containing water by tying the other end of the thread to a laboratory stand. The solid should be completely submerged in water and should be atleast 0.5 cm below the surface. Now heat the water with the solid suspended in it [Fig. E 17.1(a)].

5. Note the least count of the thermometer. Measure the temperature of the water taken in the calorimeter. Record the temperature $t_1$ of the water.

6. Let the liquid in the beaker boil for about 5-10 minutes. Now measure the temperature $t_2$ of the liquid with the other thermometer and record the same. Holding the solid with the thread tied to it remove it from the boiling water, shake it to remove water sticking on it and quickly put it in the liquid in the calorimeter and replace the lid immediately [Fig. E 17.1(b)]. Stir it with the stirrer. Measure the temperature of the liquid once equilibrium is attained, that is, temperature of the mixture becomes constant. Record this temperature as $t_3$.

## OBSERVATIONS

| | | |
|---|---|---|
| Mass of the empty calorimeter with stirrer ($m_1$) | = ... g | |
| Mass of the calorimeter with liquid ($m_2$) | = ... g | |
| Mass of solid ($m_3$) | = ... g | |
| Initial temperature of the liquid ($t_1$) | = °C | = ... K |
| Temperature of the solid in boiling water ($t_2$) | = °C | = ... K |
| Temperature of the mixture ($t_3$) | = °C | = ... K |
| Specific heat capacity of material of calorimeter $s_1$ | = ... J kg$^{-1}$ °C$^{-1}$ (J kg$^{-1}$ K$^{-1}$) | |
| Specific heat capacity of solid ($s_0$) | = ... J kg$^{-1}$ K$^{-1}$ | |

## CALCULATIONS

1. Mass of the liquid in calorimeter $(m_2 - m_1)$ = ... g = ... kg
2. Change in temperature of liquid and calorimeter $(t_3 - t_1)$ = ... °C
3. Change in temperature of solid $(t_2 - t_3)$ = ... °C

   Heat given by solid in cooling from $t_2$ to $t_3$.

   = Heat gained by liquid in raising its temperature from $t_1$ to $t_3$ + heat gained by calorimeter in raising its temperature from $t_1$ to $t_3$.

   $m_3 s_o (t_2 - t_3) = (m_2 - m_1)\, s\, (t_2 - t_1) + m_1 s_1 (t_3 - t_1)$

   $$s = \frac{m_3 s_0 (t_2 - t_3) - m_1 s_1 (t_3 - t_1)}{(m_2 - m_1)(t_2 - t_1)} = \ldots \text{ J kg}^{-1}\ {}^\circ\text{C}^{-1}$$

## RESULT

(a) The specific heat of the given solid is ... J kg$^{-1}$ K$^{-1}$ within experimental error.

(b) The specific heat of the given liquid is ... J kg$^{-1}$ K$^{-1}$ within experimental error.

## PRECAUTIONS

1. Physical balance should be in proper working condition and ensure that there is no zero error.
2. The two thermometers used should be of the same range and least count.
3. The solid used should not be chemically reactive with the liquid used or water.
4. The calorimeter should always be kept in its insulated cover and at a sufficient distance from the source of heat and should not be exposed to sunlight so that it absorbs no heat from the surrounding.
5. The solid should be transferred quickly so that its temperature is same as recorded when it is dropped in the liquid.
6. Liquid should not be allowed to splash while dropping the solid in it in the calorimeter. It is advised that the solid should be lowered gently into the liquid with the help of the thread tied to it.
7. While measuring the temperature, the thermometers should always be held in vertical position. The line of sight should be perpendicular to the mercury level while recording the temperature.

## SOURCES OF ERROR

1. Radiation losses cannot be completely eliminated.
2. Heat loss that takes place during the short period while transferring hot solid into calorimeter, cannot be accounted for.
3. Though mercury in the thermometer bulb has low specific heat, it absorbs some heat.
4. There may be some error in measurement of mass and temperature.

## DISCUSSION

1. There may be some heat loss while transferring the solid, from boiling water to the liquid kept in the calorimeter. Heat loss may also occur due to time lapsed between putting of hot solid in calorimeter and replacing its lid.
2. The insulating cover of the calorimeter may not be a perfect insulator.
3. Error in measurement of mass of calorimeter, calorimeter with liquid and that of the solid may affect the calculation of specific heat capacity of the liquid.
4. Calculation of specific heat capacity of the liquid may also be affected by the error in measurement of temperatures.
5. Even though the metal piece is kept in boiling water, it may not have exactly the same temperature as that of boiling water.

## SELF ASSESSMENT

1. What is water equivalent?
2. Why do we generally use a calorimeter made of copper?
3. Why is it important to stir the contents before taking the temperature of the mixture?
4. Is specific heat a constant quantity?
5. What is thermal equilibrium?

**SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES**

We can verify the principle of calorimetry, if specific heat capacity of the solid and the liquid are known.